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FLORA OF THE HERMIT SHALE, GRAND CANYON, ARIZONA

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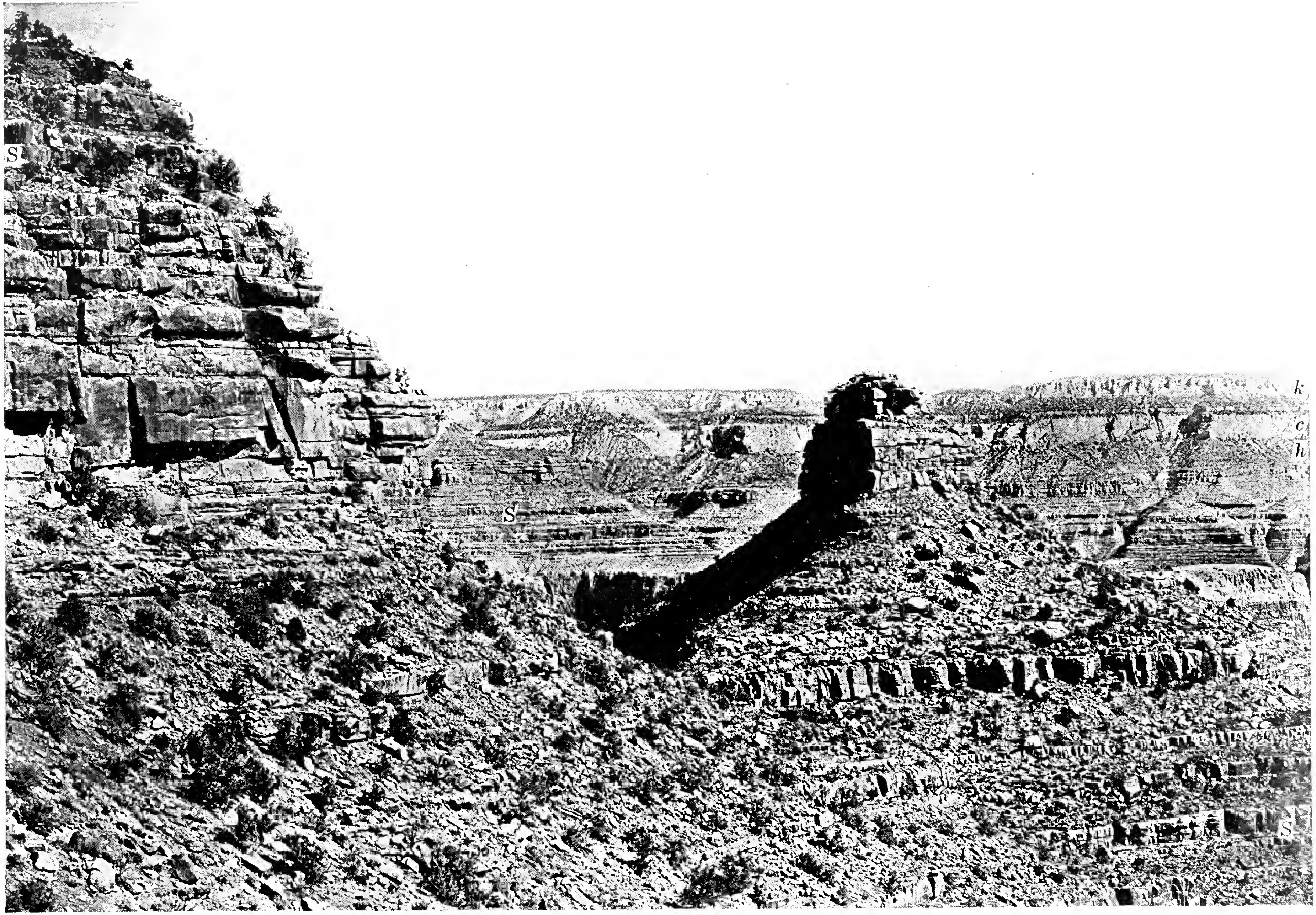


Upper walls of the Grand Canyon from the level of the upper part of the Supai formation. "Esplanade sandstone" at the left and in "the battleship" (viewed endwise in the center of the photograph). Courtesy of N. H. Darton, U. S. Geological Survey.

S, Supai formation; *h*, Hermit shale; *c*, Coconino sandstone; *k*, Kaibab limestone.

FLORA OF THE HERMIT SHALE, GRAND CANYON, ARIZONA

INTRODUCTION

Fossil plants were first discovered in the Hermit shale at Red Top, in Hermit basin in the Grand Canyon by Professor Charles Schuchert, of Yale University, in 1915. The specimens, representing *Callipteris, "Gigantopteris,"*[1] *Sphenophyllum* and *Walchia,* were sent, in 1916, to me for determination, and my report on them, in which they are regarded as probably Permian, was published by Professor Schuchert in the American Journal of Science, 4th ser., vol. 45, 1918 (page 353).[2] In 1916 Dr. L. F. Noble, who was then engaged in mapping the geology of the Shinumo quadrangle[3] for the U. S. Geological Survey, gathered a small number of specimens which also were submitted to me for examination, the conclusion being as before. However, a few more specimens gathered by Dr. Noble, in 1920, left the age no longer in doubt.[4]

These discoveries, though meager, were sufficient to prove that the Hermit shales, formerly included in the upper part of the Supai formation and classed, together with the overlying Coconino sandstone and the Kaibab limestone, as Pennsylvanian, were definitely of Permian age. What is more important, they gave evidence of the presence of a Permian flora of much interest as well as possible systematic significance.

No further collections of plants were made at the Grand Canyon until the early spring of 1926, when C. W. Gilmore, of the U. S.

[1] The imperfect impression thought at first to be *Gigantopteris* is probably referable to *Supaia.*

[2] "The condition of preservation of the fragments is so bad that caution is necessary in basing conclusions of any kind on the material submitted. However, the presence of *Gigantopteris, Walchia,* and probably *Callipteris,* if my tentative generic identification of the latter is correct, points to the lower Permian age of the flora. * * * In any event, it appears probable that the flora, when it is better known, will be found to indicate a level not below the highest stage of the Pennsylvanian."

[3] *The Shinumo Quadrangle, Grand Canyon District, Arizona,* U. S. Geol. Survey Bull. 549, 1914.

[4] L. F. Noble, *A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail,* U. S. Geol. Survey Prof. Paper 131, 1923, page 66: "A close inspection shows it to belong to the genus *Callipteris,* which, the world over, is everywhere recognized as the most characteristic and widespread exclusively Permian plant. I judge that the specimen is not even varietally distinguishable from *Callipteris conferta.* Accordingly, this evidence practically confirms conclusively the opinions based on fragments previously collected by you and Professor Schuchert and is of itself probably adequate to prove the Permian age of the Hermit shale. Taken in connection with the plant fragments previously transmitted by Professor Schuchert and yourself, it can be only Permian."

National Museum, who was collecting fossil footprints from the lower part of the Hermit, obtained a number of specimens of *Sphenophyllum,* more or less immersed in the track-bearing silts. He also found fragments of *Callipteris* and *Supaia.* The footprint shown on Plate 1 was collected by him at that time. Almost immediately thereafter, through the good offices of Dr. John C. Merriam, President of the Carnegie Institution of Washington, who was stimulating interest in the development both of the scientific resources and of the inspirational and educational possibilities of the Grand Canyon, funds were allotted by the Carnegie Corporation of New York to the Carnegie Institution of Washington to cover the travel and field expense necessary to making a collection of fossil plants from the Hermit shale. Accordingly the first systematic collecting was done in the summer of 1926. Most of the specimens in the collections were secured in June of that year.

Additional material was found during another short trip in June of the following year, when attention was given also to the successful search for traces of life in the lower part of the Unkar, Proterozoic, series found in the downfaulted blocks near the suspension bridge and on the west side of Bright Angel Creek. The development of a fossil plant quarry in the Hermit shale near the Yaki trail brought to light further specimens, without, however, appreciably increasing the number of species.

During a third short season, in 1928, funded, like the preceding, through the Carnegie Institution of Washington, I found opportunity not only to confirm the continuance of the Hermit plant beds in the north rim of the Canyon near the new Kaibab trail, but also to prove the extension of another plant-bearing stratum in the middle of the Supai formation from south to north across the Canyon, where, from the splendid exposures along the northern trail, fragments of *Walchia* may be gathered in considerable numbers. The greater part of the time of this visit was spent in the paleobotanical search of the Supai and the older formations, including the Proterozoic, for fossils, and in the selection of materials for the "geologic column" and the exhibits in the Observation Station then being built on Yavapai Point under the joint auspices of a committee of the National Academy of Sciences, under the Chairmanship of Dr. Merriam, and the Committee on Outdoor Education of the American Museums Association, Dr. H. C. Bumpus, Chairman, with funding of the construction by the Laura Spellman Rockefeller Memorial and of the equipment and exhibits by the Carnegie Corporation of New York.

The search of the shales and sandstones of the Supai formation, mainly along or near the Yaki trail, gave very meager results except

the discovery of two new footprint horizons and some zones of lenticular limestone in which the lime was deposited about and apparently through the agency of fresh-water or possibly brackish-water algæ. Fragments of land plants, generally obscure, were, however, collected from within 30 feet of the base of the Supai, and these revealed the presence of *Walchia* and *Tœniopteris* in association with several coal measures genera of fossil plants which are known to have survived into the lower Permian.

The general character of the flora of the Hermit was sketched before the National Academy of Sciences in April 1927,[1] and brief announcements of the progress of paleobotanical explorations in the Canyon have appeared in the Year Books of the Carnegie Institution,[2] besides a short note on the pre-Paleozoic fossils which was presented to the National Academy of Sciences in April 1928.[3]

My thanks are expressly due to Dr. John C. Merriam, President of the Carnegie Institution of Washington and Chairman of the Committee on National Parks of the National Academy of Sciences; to the trustees of the Institution; to Mr. J. R. Eakin, former Superintendent, and to Mr. Miner R. Tillotson, present Superintendent, and his associates in Grand Canyon National Park, for interest, cooperation and constructive assistance in connection with my work at the Canyon. In all the geological and palæontological field exploration I was fortunate in having the enthusiastic and capable assistance of the late Glen E. Sturdevant, Park Naturalist, whose work of making known to the public the scientific and educational interest of the Park had but fairly begun at the time of his lamentable death by drowning in February 1929, while exploring the geology, archæology and fauna of the Canyon west of Bright Angel Creek.

To the U. S. Geological Survey and the Chief Geologist, W. C. Mendenhall, who has most effectively cooperated in this project, I am especially indebted for the opportunity to describe the collections, and for photographs and service in completing the plates.

The specimens described in the report are deposited in the U. S. National Museum, in accordance with the wish of the Trustees of the Carnegie Corporation.

[1] *The Flora of the Hermit Shale in the Grand Canyon, Arizona,* Proc. Nat. Acad. Sci., vol. 13, No. 8, Aug. 1927.

[2] Carnegie Inst. Wash. Year Book No. 26, 1926-27, pages 366-369; and No. 27, 1927-28, pages 389-390.

[3] *Algal Deposits of Unkar Proterozoic Age in the Grand Canyon, Arizona,* Proc. Nat. Acad. Sci., vol. 14, No. 7, pages 597-600, July 1928.

I. GEOLOGICAL ENVIRONMENT

FORMATIONS IN UPPER PART OF THE CANYON WALLS

KAIBAB LIMESTONE

From any point near Grand Canyon Station, Arizona, he who begins the descent into the Canyon of the Colorado River passes first over ledges of nearly horizontal limestone strata. These blue and gray limestones, piled in cliffs forming the brow or rim of the Canyon, extend down about 550 feet and are collectively known as the Kaibab limestone. The strata are mostly sea deposits and contain fossil remains of sea shells, crustacea, corals, worms, etc., laid down in Permian time—the last epoch of the Paleozoic. Among the fossils to be found in beds not far from the level on which the observer stands are the shells of one of the last survivors of the trilobites, a group which is common in the Lower Cambrian, and must have had its origin during a great era before the Paleozoic. Fossil sponges are abundant in the thick blocky strata near the middle of the Kaibab limestone, while near the top of the lower third of this great limestone wall a band of soft reddish or pink and light buff sands is seen, which frequently forms a narrow talus slope underlain by high precipices. The full significance of these poorly cemented sands, which are cross-bedded, and which carry travertines in some places together with conglomeratic fragments of limestone, sandstone and shale derived from older formations, is not yet definitely known. Undoubtedly, however, they are due to a movement of uplift of the region slightly above sea-level followed by slow sinking, during which these red and gray sands were laid down as wash and detritus brought from some higher area of erosion, possibly not far distant. The sands are like those of the buff sandstone and the red sands and shales that successively underlie the Kaibab limestone, and may have been derived either from them or from common sources. The Kaibab is the top formation in the background of Plate A.

In passing eastward toward Colorado, the Kaibab limestone becomes interlarded with red shales and sandstones which bear evidence of greater nearness to the region from which, by erosion, the continental sediments were derived.

COCONINO SANDSTONE

Immediately under the Kaibab limestone and with sudden change both in the color and composition is a deposit of pale buff,

fine-grained sandstone, over 375 feet thick, which forms a band of light-colored, nearly vertical cliffs contouring the Canyon walls around the promontories and in and out of the gulfs and reentrant angles of the canyon. This light band, which is known as the Coconino sandstone, is conspicuous from any point on the rim of the canyon and is especially easy to locate, since it lies immediately above the broad zone of red beds which forms the middle portion of the upper canyon walls. Both with the bluish-gray Kaibab limestone, on top, and the red (Hermit) shale, beneath, it contrasts as strongly in structure as in color; for, while the blue-gray limestone above is laid down in nearly level strata, which in the cliff face suggest a wall in which the rock courses vary in thickness and hardness and are sometimes even marked off by layers of mortar-like chert, the sand of the Coconino shows but very distant and often only faint traces of horizontal stratification.

The Coconino sandstone is mainly composed of imbricating parallel thin sheets of light buff-gray sand lying one against another like the shingles of a roof, though overlapping nearly their entire length and sloping generally to the south or south-southwest at an angle of about 20 to 25 degrees to the horizontal. These southward inclining sand layers really form very thick—sometimes enormous—horizontal tiers, which, themselves, correspond to normal stratification. The thin, parallel, pitching layers, some of which are less than 0.5 inch thick, are "cross-bedding," and represent "foreset" beds built out on the advancing front of the tier, which was in general extending toward the south. The tiers in which the foreset beds lie like the leaves of a tilted book, vary from a few feet to possibly 40 or even 60 feet in thickness. The Coconino sandstone is remarkable for the scarcity and thinness of layers of normal horizontally laid sand, or "topset" beds. These mark the levels of transfer of sand along the surface of a tier to the region of final foreset deposition. Another not less remarkable feature of the Coconino sandstone is the absence of argillaceous strata or of silts. No shales are seen in the cliffs of this formation in the central Grand Canyon area.

The Coconino sandstone thins toward the northwest, the source of its sand, and thickens for a long distance to the southeast.[1]

The sand grains of the Coconino are small and, as shown in Plate D, figure 4, are rather uniform as to size. They are partially cemented by silica. By some geologists they are supposed, and possibly with good reason, to represent desert or dune sand; but by others they are believed, quite correctly as I view them, to have been laid down in water, though the sand may have originally been

[1] L. F. Noble, U. S. Geol. Survey Prof. Paper 150-C, page 60, 1928.

washed from dunes and flushed out to the area of its present deposition.

The Coconino has not yet disclosed any remains of sea shells or other clearly marine life in this region, unless certain trails of worms and crustaceans and some obscure markings suggestive of algæ were made by marine types. Its sands were probably laid down on a great plain, which verged eastward into the sea. The lack of fossils of the common types is, however, made more than good by a wealth of rather extraordinary features, for the pitching surfaces of the "foreset" beds in the lower 170 feet of the formation are marked by the footprints of great numbers of vertebrate animals. These footprints, many of which are preserved in remarkable perfection, have been recognized by C. W. Gilmore, of the U. S. National Museum, as belonging to about twenty species, representing several genera and families of extinct amphibians and primitive reptiles.[1] Many of the tracks are small and delicate as those of birds; others are large as the feet of a large mastiff. Curiously enough, as Mr. Gilmore points out, practically all of these animals were climbing "up hill" on the "foreset" slopes. They left their footprints on the sand when it may have been moist. Then the sand was presumably baked; otherwise the prints might not have been preserved in such perfection. No other remains, such as bones, scales, teeth, claws, or spines, of the animals that left these foot impressions have yet been found in this region—a very remarkable fact. Patient search in the Grand Canyon may bring to light portions of the actual animals.

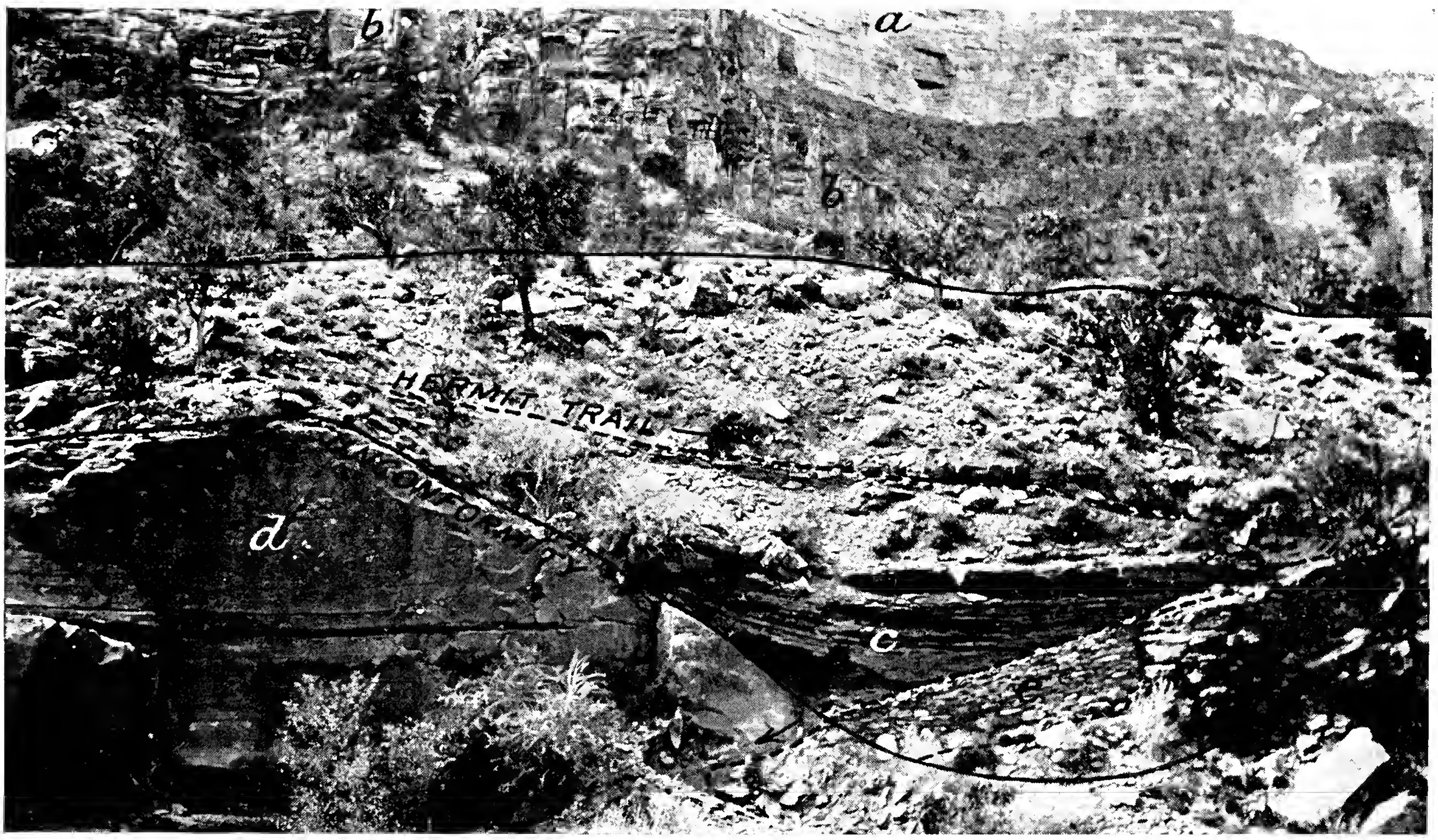
HERMIT SHALE

As is readily seen along the trails near Grand Canyon station, the first (lowest) bed of the Coconino sand to be deposited was spread out over a remarkably level and smooth surface of red silts, sands and shales of the Hermit shale (see Plate C, figure 1).

In some areas this red surface, which was slightly muddy, seems to have been intensely shrunken and cracked to extraordinary depths, as though under very intense heat of the sun. Irregular fissures or "sun-cracks" reaching a maximum width of over 15 inches and extending downward to depths of 25 feet or more into the red rock material of the Hermit may be seen on the west side of the Bright Angel trail[2] and in other exposures in this part of the Canyon walls, as shown in plate C. They were filled with the inswept light-colored Coconino sand, now cemented by silica so as to form quartzite (Plate D, fig-

[1] *Fossil Footprints from the Grand Canyon,* Smith. Misc. Col., vol. 77, No. 9, 1926; *Fossil Footprints from the Grand Canyon: Second Contribution,* op. cit., vol. 80, No. 3, 1927.

[2] See photograph by Charles Schuchert, Amer. Jour. Sci., 4th ser., vol. 45, 1918, page 351.



View of Hermit shale at Redtop, Hermit basin

d, "Esplanade sandstone"; *c,* lower beds of Hermit shale deposited in the erosional hollow, or old arroyo, in the Esplanade; *b,* Coconino sandstone; *a,* Kaibab limestone. Photograph by L. F. Noble; reprinted from U. S. Geological Survey Professional Paper 131-B.

ure 3). This sand filling, like a dyke, is continuous at the top with the Coconino sandstone and contrasts very strongly with the dark blood-red Hermit. That the fissures once stood open before the outspread of the Coconino sand is shown by "inclusions" or infallen pieces of red shale, caught in the light-colored sand in the deep cracks. The irregular branching of the fissures in different directions horizontally and their distribution in the Canyon seems to preclude their explanation by earthquake. More resistant to the weather than the surrounding red silts, these crack fillings now stand out in impressive testimony of a withering sun. The texture of the fissure fillings is shown in Plate D, figure 3, and that of the surrounding Hermit silts in Plate D, figure 2, which represents some of the most "lumpy," fine-grained and ferruginous matter within two feet of the base of the Coconino sandstone. The great size of these shrinkage cracks is the more remarkable in view of the proportion of sand in the composition of the red sediments which were evidently in a colloidal state. The cracks present a notable geological exhibit, interesting and valuable for use in the interpretation of the climatic and other environmental conditions under which the first Coconino sands were laid down.

The sun-cracked floor on which the Coconino sandstone rests is the top of a great series of red shales and sandstones forming the canyon wall down through a vertical distance of approximately 1,175 feet. In general effect this succession of red beds, which were formerly included in the Supai formation, approaches a warm blood-red, slightly suffused with orange. It stands out in vivid contrast with the pale buff-gray Coconino capping and, on account of its color, it is the most conspicuous of the rock series in the Canyon walls. It also is the thickest of the several series of beds above the inner gorge of the Canyon.

The upper part, embracing about 225 to 325 feet of this red series of shale and sandstones, comprises the Hermit shale, as already noted. This formation, which contains the fossil plants which form the subject of this paper, will be described more in detail in later paragraphs.

SUPAI FORMATION

The red beds of the Supai proper and the Hermit shale are the great sources of paint from which the lower formations have received their redness. The grains of fine sand that compose most of the strata are covered with thin films of red iron oxide, which accounts for their color; and when, during heavy rains, the sandstones and shales are swept by downpouring torrents, the water loosens and picks up the very fine and poorly cemented sand particles, so that sometimes the stream becomes, in effect, a flood of paint, which in the

bright sunlight has nearly the color of pigeons' blood. The downstreaming red water washes across the edges of the underlying gray sandstones and blue and gray limestones, and, in many of the cliffs, stains the outcropping surface of the latter to nearly as dark a red as the Supai beds themselves. This is particularly true of the two limestones beneath the Supai, the upper of which bears the name Redwall, though the rock series, about 550 feet thick, is mostly bluish gray beneath the deeply painted surface. The still lower limestone, known as the Muav, which is nearly as light colored as the other, is less completely stained on the outcrop.

Thus it is seen that the internally red formations of the Canyon wall above the Tonto platform are for the most part confined to a thickness of about 1,100 feet, and that the redness of much of the outcrops of 800 feet of underlying limestones and portions of the still lower greenish and bluish Cambrian shales resting on the Tonto (Cambrian) platform is only superficial and borrowed from formations higher in the walls.[1] This accounts for the predominance of redness in all illustrations showing the Canyon in colors.

Groups of sand strata, some of which are thick and light gray, characterize the lower and middle portions of the Supai, and on some of the bedding planes of a fifty-foot massive white ledge of the middle sandstone group, remarkably distinct and interesting tracks of vertebrate animals were found by Dr. John C. Merriam, G. E. Sturdevant and C. W. Gilmore. These tracks, which have been described by Mr. Gilmore,[2] represent species which are all different from those found either in the lower part of the Coconino sandstone or the beds near the top of the red series. Some of the sandstones lower in the Supai formation also contain footprints. Traces of plants, including *Walchia* and *Rivularites,* are found at several levels, and fragments of *Walchia, Tæniopteris, Neuropteris, Cordaites* and *Calamites* are found in the red shales and sandstones about 25 feet above the base of the Supai, as it is exposed just east of the Yaki trail.

The red shales, both above and below the great track-bearing ledge in the middle of the Supai and below the next lower sandstone ledge, contain irregular bluish concretions or branching nodule-like masses of blue lime formed through the agency of lime-depositing algæ. In some of these masses the thread-like algæ scattered throughout the lime are clearly seen by means of a weak lens.

The upper and middle parts, at least, of the Supai are terrestrial deposits—laid down on an old floodplain. Marine mollusca have not

[1] Thin zones of the Cambrian shales are reddish or pinkish, but these are inconspicuous.

[2] *Fossil Footprints from the Grand Canyon: Second Contribution,* Smith. Misc. Col., vol. 80, No. 3, 1927; *Fossil Footprints from the Grand Canyon: Third Contribution,* op. Cit., vol. 80, No. 8, 1928.

yet been found above the beds very close to the bottom of the formation.

In the basal part of the Supai are found thin, irregularly lenticular deposits of limestone formed about aggregations of calcareous algæ, some of which, now silicified, weather into relief, when they resemble skeins of yarn. The occurrence of the alga beds in the middle and lower portions of the Supai lends no support to the view, held by some geologists, that the greater part of this series of red beds is desert deposits laid down by the wind, though it is very probable that the climate of the great floodplain was marked by dry, hot summers; also that the surfaces of the deposits were exposed at times. During some of the time the climate may have been semiarid. Certain small, white, nodular aggregates in the upper part of the formation will perhaps be found to have likewise been formed by colonies of lime-forming algæ.

About 275 feet below the top of the red-bed series—i.e., below the base of the Coconino sandstone—is a group of rather hard, dark-red sandstones of an aggregate thickness of about 270 feet, which represent the topmost deposits of the Supai formation as the upper boundary of the latter is now drawn. Being more resistant to erosion than the overlying beds of the Hermit shale, the sandstones form a group of high red cliffs, above which the softer shales have been worn away so as to produce a shelf or bench. This shelf, which may be followed along the contours of the Canyon, affords convenient routes for trails around the promontories and coves, and, on account of its scenic relations in the Canyon walls, it is known as the Esplanade.[1] Accordingly, for convenience of reference, the group of hard sandstones which supports and forms this shelf is termed the "Esplanade Sandstone." It is a purely local member of the Supai formation. This sandstone, which lies just beneath the Hermit shale, is displayed especially well in the Hermit basin, where it plays a leading rôle in producing the picturesque effects in the vicinity of the Santa Maria spring.

REDWALL LIMESTONE

In the region about Grand Canyon station the Supai rests on an old limestone surface pitted with sinkholes and underlain with caverns before the red sands were laid down. These limestones, about 500 feet thick, are purplish and greenish glassy at the top, the lower beds being bluish or gray. All are marine and carry shells and other fossils characteristic of the Carboniferous, mainly the Lower Carboniferous, or Mississippian.

[1] See L. F. Noble, *The Shinumo Quadrangle, Grand Canyon District, Arizona,* U. S. Geol. Survey Bull. 549, pages 21-73, 1914; also, *A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail,* U. S. Geol. Survey Prof. Paper 131-B, page 61, 1923.

MUAV LIMESTONE

Immediately beneath the Redwall, but generally separated from it by thin purplish limestones or shallow hollow-filling pockets of fish-bearing Devonian sandy limestone, is found another series of limestone, dove-colored, slightly drab and gray, and containing more marine shells. These beds, about 385 feet thick, are shown by the fossils to be of Upper Cambrian age. Though the limestones of the Muav often lie in contact, parallel, with the Mississippian Redwall limestone over considerable areas, a vast extent of time, embracing the Ordovician and Silurian periods as well as most of the Devonian, elapsed between the periods of their deposition. During most of this long hiatus in deposition this area of the continent was above sea-level and probably undergoing erosion.

Together, the Redwall and the Muav limestones form the massive vertical cliffs that compose the buttresses of the temples and promontories of the Canyon walls. They combine, often with only a narrow stepbreak, in producing the most precipitous and nearly impassable of the many cliffs of the Canyon side.

BRIGHT ANGEL SHALE

The Muav limestone grades downward into bluish and greenish sandy shale with a few interspersed limestones (the sources of most of the springs of this vicinity) and sandstones, in all about 325 feet,[1] called the Bright Angel shale. These are marine, and are characterized by immense numbers of casts of slender, "ropy," intermingled and intertwined seaweeds. The lower part of the shale contains several thin dirty-brown sandy layers carrying Trilobites and marine mollusca, which prove that this formation, also, is of Upper Cambrian age.

The beds of the Bright Angel shale are generally relatively soft and wear back in long slopes extending from the foot of the Muav-Redwall cliffs down to the top of the Tapeats sandstone which rims the inner Canyon of the Colorado River.

TAPEATS SANDSTONE

Rusty, brownish-gray sandy flags, often suggesting masonry, underlie the Bright Angel shale. They are resistant to erosion and consequently stand in cliffs, sometimes 250 feet high, forming the brink of the inner gorge. These sandstones contain great numbers of the casts of seaweeds, called "fucoids." They are wave-marked, and where the lower beds were laid down on the Vishnu schist we find conglomerates containing pebbles of schist and other older rocks as well as quartz, the latter being often rusty yellow or saffron in color.

[1] This thickness, on Bright Angel trail, is quoted from L. F. Noble, *loc. cit.*, p. 72.

The Tapeats sandstone was deposited off a vast, low, flat coast, which was sinking slowly beneath an Upper Cambrian sea.

Detailed descriptions, with measurements of the formations in the Canyon walls, are given by L. F. Noble in *A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail* [1] and in *The Shinumo Quadrangle, Grand Canyon District, Arizona.*[2]

THE HERMIT SHALE

The Hermit shale, which embraces the upper part of the great red series in the upper part of the Canyon walls, lies between the base of the gray Coconino sandstone above and the top of the sandstone forming the Esplanade beneath.

The formation thickens to the westward. On the Yaki trail it is said to be 225 feet. It measures 260 feet in Bright Angel trail and about 275 feet in the Hermit Basin.

CONDITIONS OF DEPOSITION OF THE HERMIT SHALE

Land Surface

As one follows along the upper surface of the "Esplanade sandstone" in the region embracing the Hermit basin and the Kaibab trail, he finds the shelf made by the top of the sandstone, 270 feet thick, to drop rather abruptly here and there in broad hollows in the sandstone. These hollows, several of which may be seen in the Hermit amphitheater, are not mere notches cut by present-day rills. They represent partially excavated erosion channels cut in the "Esplanade sandstone" before the overlying shales were laid down. They are irregular in distribution and size and are nowhere observed to be more than 70 feet deep, nor apparently more than a half mile in width in this region. They are well seen in the Hermit basin as one looks across from points on the Hermit trail below Red Top and in the vicinity of the Santa Maria Spring, where they have been described and illustrated by Noble.[3] In fact, the trail descends through one of these hollows, now partly emptied, in the Esplanade at "Red Top" (Plate B,—opposite p. 8).

Close examination of these hollows shows that they are filled by softer beds, less resistant to erosion, like those overlying the big sandstone; also the shales are more silty and are slightly less brown, and of a warmer red tone than the "Esplanade sandstone" in which the hollows are cut. These "filling" deposits compose the lowest part of the Hermit shale. They abut horizontally against the edges of the

[1] U. S. Geol. Survey Prof. Paper 131-B, 1923 (See plates XIX and XX).

[2] U. S. Geol. Survey Bull. 549, 1914, page 72. See also N. H. Darton, *Guidebook of the Western United States, Part C, The Santa Fe Route, with a Side Trip to the Grand Canyon of the Colorado,* U. S. Geol. Survey Bull. 613, 1915.

[3] L. F. Noble, U. S. Geol. Survey Prof. Paper 131-B, page 63, pl. 33B, pl. 34A.

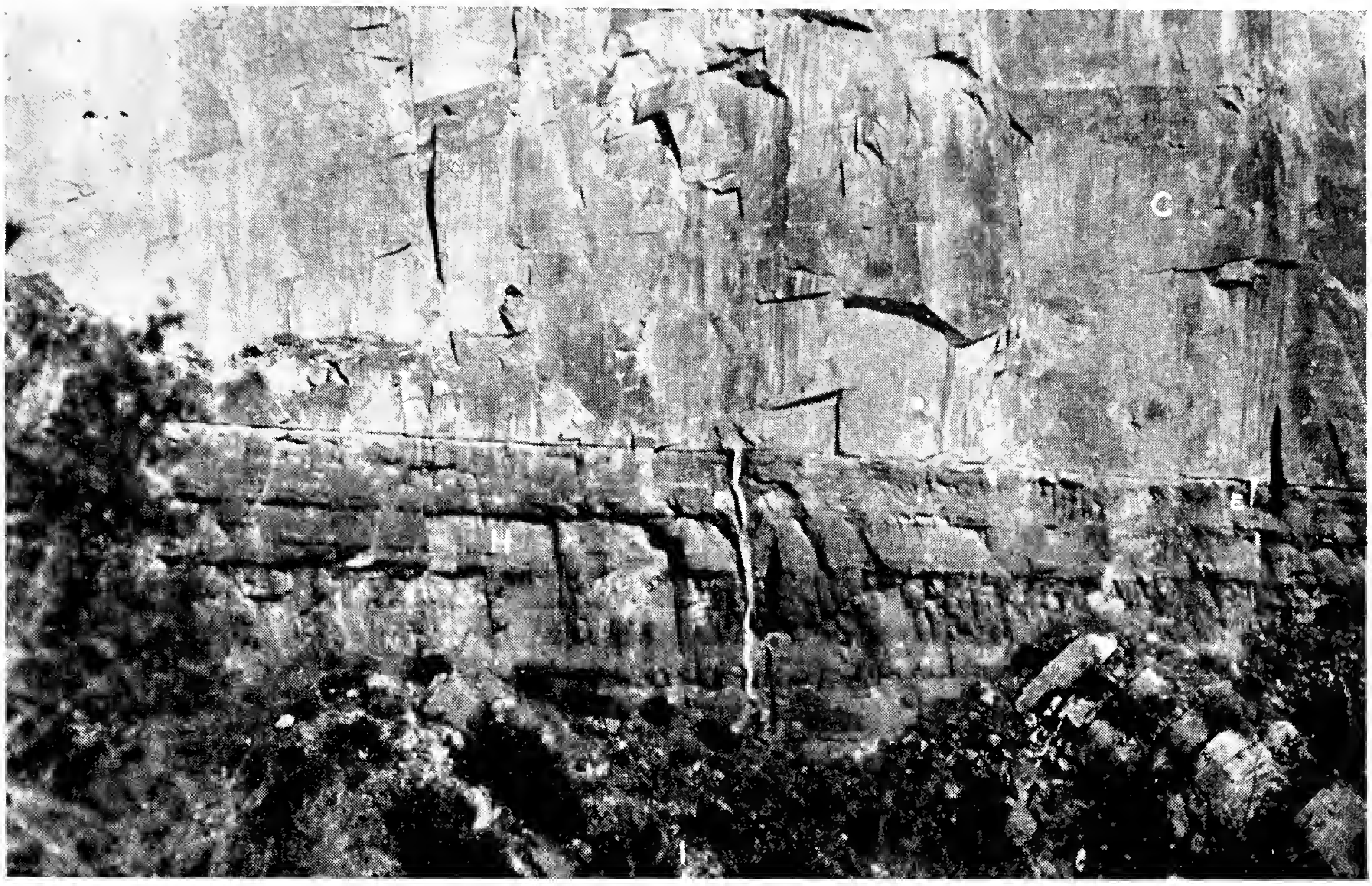
Esplanade sandstones on the bottoms and at the sides of the hollows. From this it is clear that, following the deposition of the Supai, the region was uplifted and the "Esplanade sandstone" subjected to cutting and trenching by streams with the formation, here and there, of shallow valleys or arroyos and small pond-like basins. Cross-sections of arroyos are shown in Plate B and Plate C, figure 2.

The Hermit shale in the Hermit Basin is found by Noble to be as much as 320 feet thick where measured from the bottom of the deepest arroyo, and but 265 feet from the intervening levels of the top of the "Esplanade sandstone."

The length of time between the deposition of the "Esplanade sandstone" and the resumption of deposition with consequent filling of the shallow arroyos by the softer Hermit shale is not known. It is, however, the belief of the writer that, in spite of the differences in the character of the filling Hermit, the erosion interval was, geologically speaking, not long, for the following reasons: (1) The new drainage had merely notched the land surface here and there, leaving broad low, flat, interstream areas which represent the original undissected surface of the Supai ("Esplanade sandstone"). No "second bottoms" indicating a physiographic history have been noted. The surface of the Esplanade may even have served as a floodplain while the arroyos were being filled. This is especially likely during the later stages of the filling process. (2) The sandstones of the Esplanade do not seem to have been hardened or lithified before the hollows were filled; for they do not appear to have furnished hard pebbles such as should form conglomerates at the base of the Hermit in the hollows and along the streams. Such conglomerates as occur, in small areas, near or at some distance above the base of the Hermit contain only small pebbles, generally of gray and blue limy rock and pellets of iron. Apparently the sands of the Esplanade were still relatively soft and subject to easy erosion and disintegration when the arroyos were filling again. As to this point it is, however, to be remembered that in certain areas, never subjected to heat or metamorphic compression, sands of the Lower Cretaceous are now friable and soft. (3) Finally, the "Esplanade sandstone" and the lower portions of the Supai in this region contain Permian plants. Though evidently older than the Hermit flora, which, as will be shown, is probably upper Lower Permian, if the Permian be viewed as comprising two major divisions, the Supai in the Bright Angel-Yaki area is, itself, nevertheless of Permian age.

Deposition and Stratification

The Hermit shale consists mainly of sandy, current-rippled, thin-bedded, sandy "shales" and silts, verging into blood-red and in part



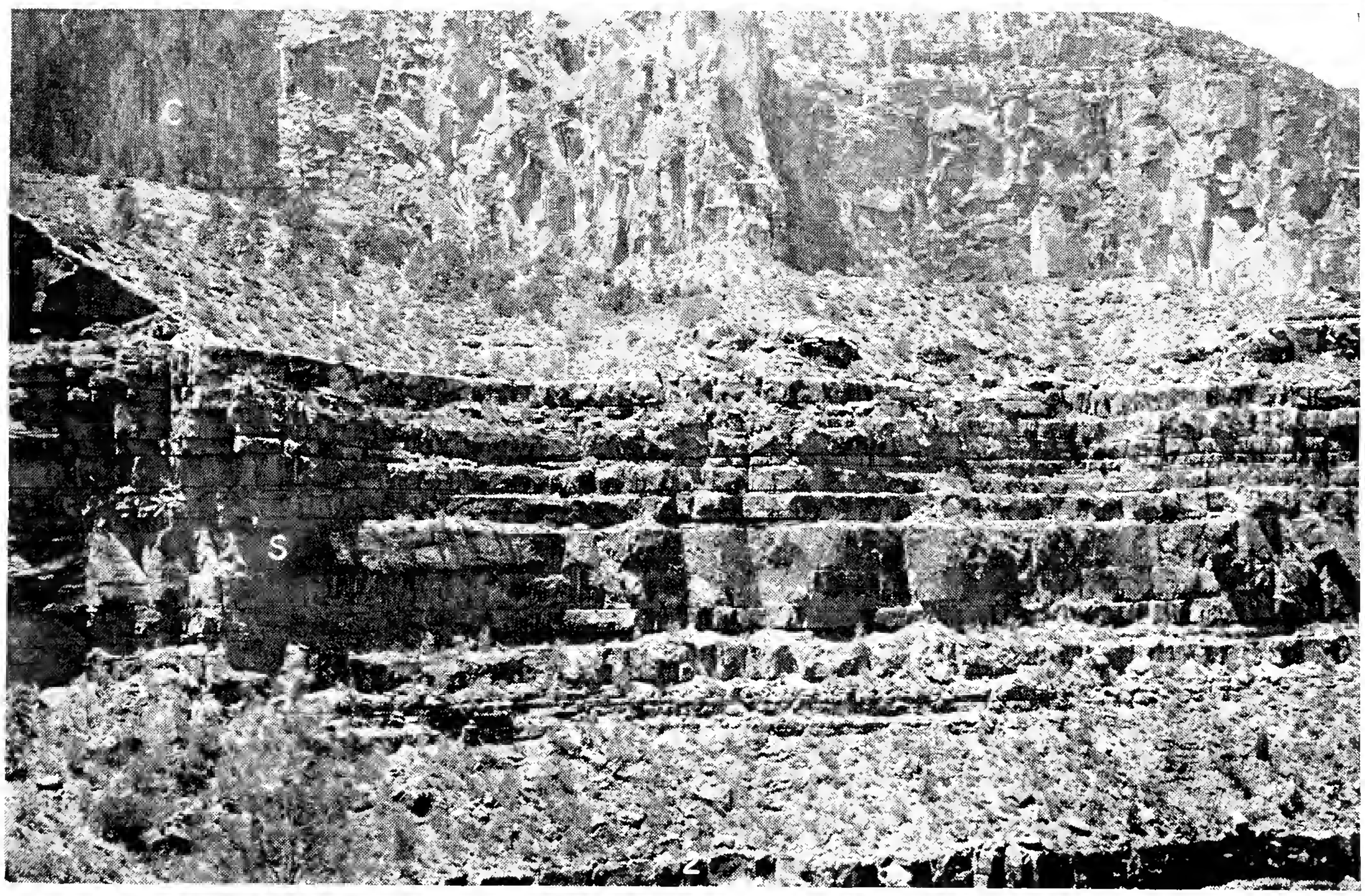


FIG. 1—View of contact of Coconino sandstone with underlying Hermit shale as seen looking west from Bright Angel Trail. Exposure shows shrinkage cracks in top of Hermit filled with cemented Coconino sand. C, Coconino sandstone; H, Hermit shale; E, shrinkage crack filled with buff-gray sand. Photograph loaned by Professor Charles Schuchert.

FIG. 2—View of west wall of Hermit Gulch from Hermit Trail near Santa Maria Spring, photographed to show cross-sections of pre-Hermit erosional hollows in top of Supai formation. Red sandstone (S), upper member of Supai formation with erosional hollows filled by basal shales of Hermit (H). Owing to recession slope of soft Hermit shales lying on sandstone of Esplanade and upward direction of line of vision, the thickness of the Hermit is greatly foreshortened in perspective. Vertical cliff (C) in upper part of view is Coconino sandstone which is surmounted by Kaibab limestone, the lower part only of which is seen. Photograph by courtesy of H. E. Stork, National Park Service.

suffused by a lighter warm tone, especially where not very fully weathered. Thin sandstones, irregularly bedded and soft, occur at several levels, especially in the hollow-fillings on the Esplanade, and in the next 50 feet of beds above the Esplanade level; also three or four soft sandstones are found near the top of the formation. All appear to lack continuity, and though the grains are generally thickly coated with iron, and more or less cemented by carbonates, the sands are soft and easily eroded. This accounts for the sloping surface from the top of the Esplanade to the foot of the light buff cliffs of the Coconino sandstone.

Field specimens accompanied by thin sections illustrating the relatively coarse deposits, the fine, stream-rippled shales, the sun-cracked silts, and the very deeply sun-cracked top zone of the Hermit shale have, together with samples of the overlying Coconino sandstone and the material filling the great cracks in the top of the Hermit, been placed in the hands of C. S. Ross, geologist in charge of petrological investigations in the U. S. Geological Survey, who has kindly furnished the microphotographs shown in Plate D, together with the following descriptive notes on the specimens.

PETROLOGICAL NOTES ON HERMIT AND COCONINO SEDIMENTS

(Plate D)

1. *Average sandy shales and silts, mostly intensely rippled.*

   Nos. 28-36-37-39 are very similar to 28-14. The proportion of dolomite varies a little, but is about 50 to 60 per cent of the rock. No. 28-37 is the coarsest grained specimen, with sand grains that average nearly 0.04 mm. in diameter ("fine-grained grit").

2. *Extremely thin-bedded, ripple marked, fine-grained silt.*

   No. 28-48. A fine-grained silt composed of sand and about 25 per cent of dolomite in the form of rhombs. The sand contains about 5 per cent of plagioclase and orthoclase and a little muscovite. The sand grains are angular to sub-angular in outline. The red pigment of the rock is composed of ferruginous and clay-like material. Some of this is in small rounded aggregates and some of it is unevenly distributed as a film around the sand grains. The rock shows bedding planes. Where the material is finer grained, there is a concentration of dolomite, and a few magnetite and ilmenite grains are present.

3. *Relatively "muddy," sun-cracked silt.*

   No. 28-14. Not very different from 28-16 in size and form of sand grains, but dolomite is very abundant as it forms about 60 per cent of the rock.

4. *Streaked, stream-rippled, silty shale* (Plate D, figure 1).

   No. 28-3. Red areas are a fine-grained sandy silt and the white ones are dominantly carbonate. Large areas were originally calcite but this has been partly replaced by small rhombs of dolomite.

5. *Very fine muddy silt and slime.*

No. 28-16. Calcareous silt composed of about 50 per cent sand grains and 50 per cent carbonate (principally dolomite). The sand grains average about 0.035 mm. in diameter and are dominantly quartz, but plagioclase and orthoclase form about 5 per cent of the rock and a small amount of muscovite is present. The sand grains are angular to sub-angular, and are surrounded by a narrow zone composed of a clay ferruginous cement.

6. *Upper two feet of Hermit shale, cut by great shrinkage cracks* (Plate D, figure 3).

No. 29-1. Very dark red ferruginous silt composed dominantly of quartz grains with abundant interstitial material composed of iron oxide with a little clay. The sand grains are very angular and are nearly 0.04 mm. in diameter. In small areas there is a local concentration of dolomite, but this material is not abundant in the rock. The quartz grains are as large or larger than those in any of the specimens, but are much less abundant, since the ferruginous cement forms about 50 per cent of the rock.

7. *Track-bearing lower portion of typical Coconino sandstone* (Plate D, figure 4).

No. 27-41 (56). Fine-grained light buff-colored sandstone. Composed dominantly of quartz but contains a little feldspar. Average diameter of grains about 0.15 mm. There is no calcareous cement and very little interstitial clay material, but a few small pellets resemble kaolin. The quartz grains were originally rounded to subangular, but have been enlarged by the addition of silica. A few grains show that crystal faces have been formed during this addition of silica.

8. *Fillings of shrinkage cracks in top of Hermit shale* (Plate D, figure 3).

1927-36 and 1929-2 are nearly alike. Sandstone composed of about 82 per cent quartz, 16 per cent of carbonate (calcite and dolomite). The quartz grains have been enlarged through the addition of silica and the average diameter is about 0.15 mm. The carbonate grains are irregular in shape and fill the interspaces between quartz grains and thus differ in form from the anhedral dolomite grains of the Hermit.

Most of the rock strata, both sandstones and shales, show cross-bedding, but here and there in the old arroyos we find thin beds of sand, usually not more than 5 or 10 inches in thickness, which were deposited very rapidly. These lack planes of stratification, due to uninterrupted deposition. In one ledge the upright fronds of a fern-like plant were thus surrounded by about 9 inches of sand, which was not, however, thick enough to bury completely the standing plant.

Great difference of opinion exists among geologists as to the conditions under which the Hermit as well as the upper part of the

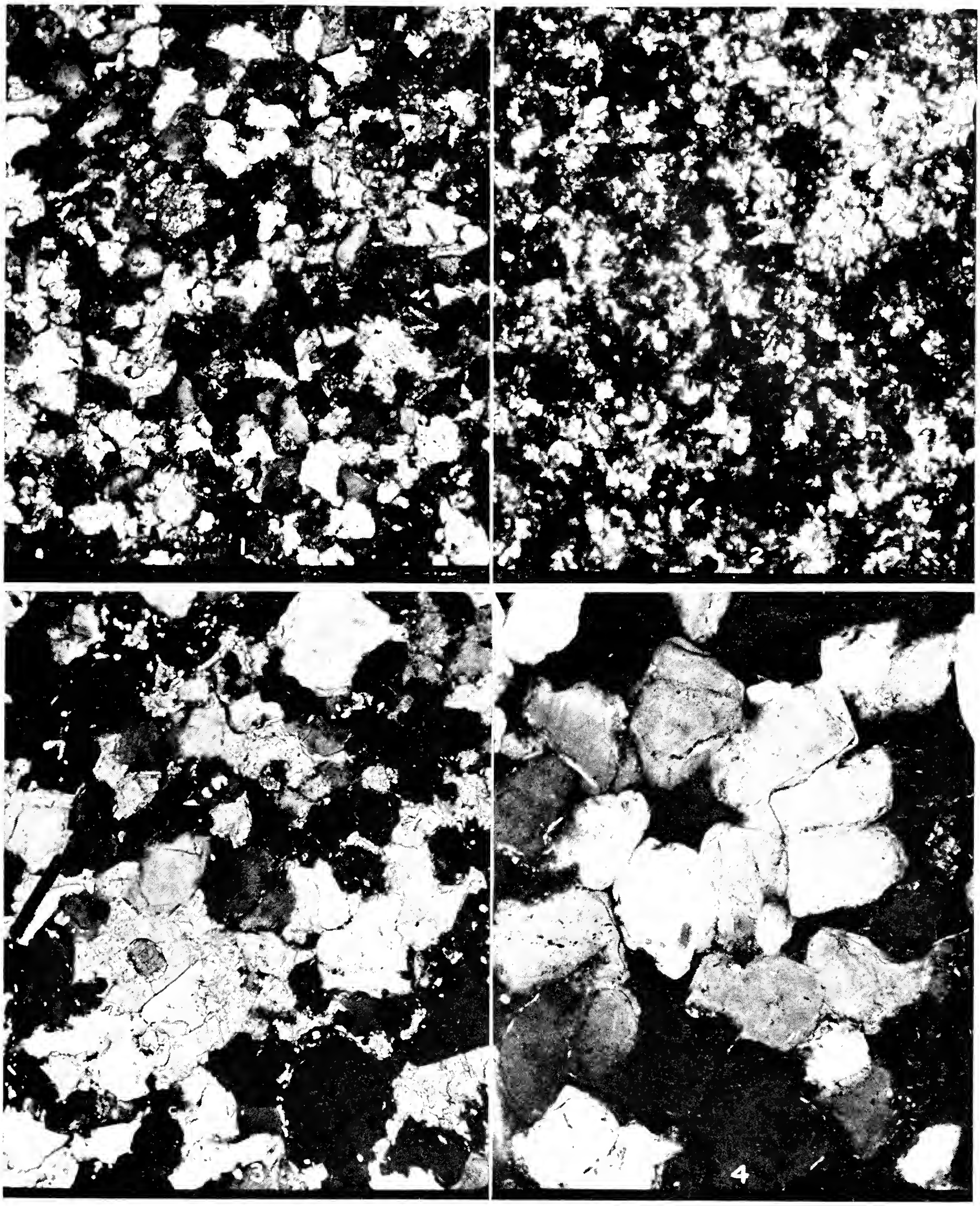


Figure 1. Photomicrograph of the coarser-grained phase of the Hermit shale. The white areas are dominantly quartz but a small proportion of feldspar is present. The areas of high relief that have a stippled appearance are calcite and the nearly black areas are a highly ferruginous argillaceous cement. × 86.

Figure 2. Photomicrograph of the upper, fine-grained, portion of the Hermit shale. The white areas are quartz and the dark ones highly ferruginous clay cement. × 86.

Figure 3. Photomicrograph of rock filling shrinkage cracks in the Hermit shale. Large white and dark areas without relief are quartz, the material with high relief that fills interspaces between quartz crystals is calcite. Crossed nicols × 86.

Figure 4. Photomicrograph of Coconino sandstone. Almost a pure quartz sandstone. The borders of the quartz grains show enlargement. Crossed nicols × 86.

Photographs by courtesy of C. S. Ross, U. S. Geological Survey.

underlying Supai were laid down, it being the belief of some that the red sand was transported and deposited by winds under desert or semi-desert conditions. Others hold that, though the sediments might have been more or less subject to wind transportation in an arid environment before final deposition, the materials forming the Hermit shale, at least, reached their present resting place by water transportation and were laid down under water. Evidence bearing on this question is found (1) in the stratification and structure of the deposits, (2) the petrographical and chemical composition of the rocks, and (3) the characteristics and habits of the life found in the deposits.

As will be seen in the following review, the facts point distinctly to water as the medium of transportation and deposition, though they indicate clearly a warm and semi-arid environment.

At the outset it is to be remembered that the Hermit shale is a thin-bedded formation. Its sands are fine, though largely angular. By far the greater part resembles thin-bedded, stream-current waved red sandy silts. No long slopes of "foreset" beds (cross-bedding), like those seen in the Coconino sandstone, are found. No long waves are present. Cross-bedding of the stream ripple type is, on the other hand, common—omnipresent, in fact. It is seen, often in great refinement, both in the thin, stiff, wavy, sandy shales, which exhibit a relatively rigid, crusty texture on some of the weathered outcrops, and in the thick shales, bedded relatively rigid and hard so as to pass for sandstones, which, in fact, they really are, in spite of the rippling and general thinness of stratification. It is, however, to be observed that on many of the angular and unsymmetrical waves, all of which are small, the very thin cross-beds, while irregularly concave downward and wedging characteristically in knife edges to the crest of the current wave, are truncated, with evidence of repeated scouring and redeposition of the fine grit, which contains limited portions only of clay. We may therefore conclude also that argillaceous matter was scarce and that sedimentation was, on the whole, rather slow.

That the sand was not wind-deposited is further shown, for the lower half at least, of the formation, by the horizontality and relative parallelism of the beds. The microstructure of the stream-rippled sand with small-scale cross-bedding is shown in Plate D, Figure 1.

CLIMATE AS INDICATED BY THE SEDIMENTS

Here and there, in what were pools or areas of relatively slack water in the arroyos, the wavy ripple layers of the shale are covered with films of silt and argillaceous matter, richer in iron and evidently laid down after slackening or stagnation of the current. They look like shiny slime surfaces, and such they are (see Plates 3 and 43). On these

slimes, which in the freshly quarried material often retain their gloss, one may find numerous trails left by fragments of debris dragged in the water, and by worms; or, perhaps, the delicate imprints in great perfection of small feet, resembling those of the "mud puppy" and belonging to some early type of salamander or batrachian (Plate 3). In many cases the slime surfaces were suncracked (Plate 2). Evidently, therefore, the footprints were made while the muds were still moist—i. e., soon after the recession, by drainage or evaporation, of the water.[1]

Sometimes small portions of plants, also, had fallen into and were partially buried in or coated with the slime films (Plate 23, fig. 1), before the mud was exposed to the air and hardened. The plant impression may be relatively distinct if found exactly in the slime layer, which may, however, be a mere thin film. Generally the fragments of the plant are badly macerated. Those portions that rose above the slime surface evidently withered and in most cases wasted away before the water was replenished. Often the thin film coats and can not be lifted from the plant whose outline is visible beneath it, as is shown in Plate 43 and Plate 12, fig. 3.

Evidence of great fluctation of the water bodies in which animals swam and leaves drifted, to be buried in inwashed sands or settling silts, is unmistakable. Suncracks abounding in the lower Hermit testify to the very frequent reduction of the water cover, and the molds of salt crystals (Plate 33, fig. 2) prove its nearly entire disappearance at times. The slimes are now hard and generally slightly darker colored than the subjacent sand, due both to the greater amounts of iron oxide and the clay content.

Reference has already been made (page 8) to the giant suncracks in the top of the Hermit (Plate C). The size and relations of the carbonate crystals in the top beds are construed as indicating the formation of these crystals as the result of evaporation of the water at time of deposition of the silts.

That the deposition in the Esplanade hollows was, however, rapid at times is shown by the irregular positions of some of the fossil stems and twigs in the deposits. These frequently lie more or less oblique to the bedding, a condition proving the deposition of sediments before the plants had wilted. The occurrence of erect stems is rare except in the case of the relatively rigid stems of the *Sphenophyllum,* which was amphibious. In many cases its stout stalks were buried in place of growth by sand laid in thin and perhaps cross-bedded sheets around them. An example of such erect stems,

[1] For illustrations and descriptions of the footprints, see C. W. Gilmore, *Fossil Footprints from the Grand Canyon: Second Contribution,* Smith. Misc. Col., vol. 80, No. 3, 1927; *Fossil Footprints from the Grand Canyon: Third Contribution,* Smith. Misc. Col., vol. 80, No. 8, 1928.

with their verticils of leaves spread out in the thin cross-bedded rock, is shown in Plate 10, figures 5 and 6. Such rapid inwashing of sand, though subject to current shifting and cross-bedding, was, of course, more favorable for the accidental entombment and burial of drifting plant debris than the thin-bedded, curly shales, but the minute features characterizing the leaf or twig are generally less distinct on account of the coarser matrix.

An interesting result of the current deposition is the not infrequent truncation of leaves or stems by current scour, in the course of which some of the sand was removed, to be redeposited in some other place, so that we have the fragments of fronds cut off more or less cleanly along the planes of current scouring, while in rare instances a part of a frond, originally deposited in one position in the sand, and soon after partly uncovered, was again buried on a new surface of deposition beneath a fresh contribution of current-laid sand, but in a new attitude and often in a disheveled state. So it happens that plant fragments are found at various angles in the rock, a fragment of one leaf being not infrequently laid down on one cross-bedding plane at an angle to the truncated portion of another frond, earlier fallen on a bedding plane of different slope. Thickness and toughness of the xerophytic leaf have aided such preservation.

Some of the cross-bedded sandstones and shales carry fragments of the twigs and branches of *Walchia,* the sprays of which, spreading out frond-like as those of the living *Araucaria excelsa* to which *Walchia* was related, were relatively stiff, the leaves being thick, strong and usually curved or inclined upward with considerable rigidity. Occasionally these twigs had dried where they rose above the surface of the sediment. Also many of the fragments of the less resistant fern-like plants found in the thin cross-bedded sandstones are torn, rumpled and crushed, despite the fact that most of them were thick and relatively rigid in structure. Evident withering is common. This agrees with the abundance of suncracks and the sunbaking of the slimes and silts when exposed by the evaporation of the water.

It is important to note that nearly all the plants found in the Hermit were such as might grow along stream banks or on the nearby land. Most of them came to their present resting places by drifting, which may largely account for their frequently disheveled condition, even when finally buried in lenses of rapidly deposited sand.[1]

[1] The conditions leading to the deposition of thin wavy, sandy shales are, in general, very unfavorable for the preservation of fossil plants, unless deposition was very rapid. In fact, well-preserved land plants are extremely rare in such deposits. The relatively good impressions left in the sand by many of the Hermit plants was doubtless due to the rigidity and leathery texture of the stems and leaves.

On the whole, the characters of the beds of the formation point clearly to deposition of the lower part, at least, of the Hermit shale under water, which was flowing probably in torrents at times, though here and there at other times were stagnant pools lined by bottom slime deposits, on which worms moved about and small batrachians left remarkably distinct footprints. That the water level fluctuated greatly is shown by suncracking, not only of the finer and more or less argillaceous layers of the shale (Plate 1), but of the silts as well (Plate 2), though to shallow depth. In fact, not only was crackling of the slime layers common, but the preservation of the slimes themselves was in many cases, at least, no doubt due to sunbaking of the material in the air, with deposition of some less soluble salts in the silts, before rising water and renewal of current movement brought new influxes of sediments, scouring away parts of those already deposited, and, in the course of time, further filling the hollows. Eventually the sand-bearing floods spread out over the surface of the vast red sand flat or floodplain, rippling above the top of the completely buried "Esplanade sandstone."

The arroyos were probably comparable to a degree to those seen on a very small scale in the red floodplain of the Puerco and Little Colorado Rivers in the region embracing Winslow, Arizona. They represented a young drainage, shallowly and distantly cut into the plain. Apparently some of the pools were at times emptied by evaporation. On the other hand, the stream gradient appears to have been light and the water may even have flowed on the flat interstream areas in times of flood.

At the time of Hermit deposition there were no rocks in the vicinity from which hard conglomeratic material, including pebbles of quartz, chert, sandstone, and limestone or lava, was washed down over the floodplain in this region. No boulders of harder rock are found to have been rolled into or along the old waterways to become embedded in the shales and sandstones. Hence, we must conclude, not only that the area in question was far from the sources of hard pebbles and that the gradient was low, but also that the "Esplanade sandstone" was at the time relatively soft and not sufficiently cemented to cause it to break down in blocks or boulders resistant to ready erosion and disintegration. Certainly the interval during which the Esplanade sandstone was subjected to trenching, before Hermit deposition began in the hollows, was not characterized by such changes as might cause the consolidation and lithification, through cementation, of the "Esplanade sandstone."

Further and perhaps more conclusive testimony of the sediments as to climate is seen in the red color of the silts and sands. Reasoning from the conditions observed to attend deposition of sediments of

different colors at the present day, red sands and silts are generally recognized, though not without exception, as marking arenaceous terrestrial deposits laid down in a warm climate characterized by long, hot, dry seasons. Redness is especially evident if vegetation or other organic matter was sparse, with conditions favorable for its oxidation, as obviously was the case with the Hermit.

The landscape of the early Hermit, while red and semi-arid in aspect, is not proved to be a desert, though, as will be seen, it lacked the humidity of most Lower Permian basins, including those of the eastern States, and probably was subject to long warm and dry summers. Molds of salt crystals are found in one of the plant beds, as shown in Plate 33, figure 2, and careful search will probably reveal traces of salts at other levels and localities, where evaporation of the arroyo pools proceeded to the point of crystallization of a part, at least, of their saline contents. Such occurrences are, however, probably rare in the Hermit. Large insects lived in the region (Plate 51, figure 2).

EVIDENCE OF THE FOSSIL PLANTS AS TO CLIMATE

In the foregoing review of the testimony of the sediments and topography as to the environment of Hermit sedimentation the criteria offered by the rocks have been found to show that in early Hermit time this region was the scene of showers, burning sun, hailstorms,[1] occasional torrents, and periods of drought and drying up of pools. The testimony of the plant life of the Hermit as to the climate of the environment in which it grew is not less definitive. As will be noted here and illustrated on later pages, the flora points to a semi-arid climate with a long dry season in this region during Hermit time.

The plants found in the Hermit were growing in the immediate vicinity where they are now found. Some of them were rooted in the sandy soil of the bottoms or lower slopes of the hollows. The flora is largely unlike any flora known from the Lower Permian or the basal Upper Permian of any other part of the world. It contains some representatives of the Old World or "cosmopolitan" Permian plant society, with which are mingled a large group of new forms whose closest relations are found in northeastern Europe and central Asia, and in the Gondwana floras of India, Australia, Africa and South America—that is, the so-called Gondwana land. The age of the Gondwana beds in which the relatives of these Oriental forms occur is disputed, but the terranes in which they are found in the Uralian and central Asian regions are of uppermost Lower Permian and Zechstein (Upper Permian) age. Here they were mingled with

[1] See impressions made by hailstones on the suncracked silts shown in Plate 2.

forms either of cosmopolitan range or peculiar to the central Eurasian province in middle Permian time. Most of the species in the Hermit flora have, however, hitherto been unknown.

Although no barriers of water are definitely known to have intervened during Hermit time between the region now embraced in northern Arizona on the one hand and the Great Plains region on the other, the Hermit flora contrasts very strongly with the Lower Permian floras of the Mid-Continent region. Quite aside from the introduction of immigrants from the Orient, it differs not only from the floras of Kansas, Oklahoma and Texas, but from the European cosmopolitan Permian floras, as well, by the absence of nearly all of the moist-climate and swamp-loving types. No representatives of the Cordaitales, mostly upland plants, or the Calamariales, which like their living relatives, the horsetails, have always favored moist and generally sandy soils, and *Sphenopteris,* or the Neuropterid genera, *Neuropteris, Alethopteris, Callipteridium* and *Odontopteris*—all present in the Lower Permian of the Mid-Continent and Appalachian regions—have yet been recognized, though, of course, traces of one or more of these groups may later come to light. We must therefore conclude either that the Hermit flora had its day after the extinction of these groups—which is hardly tenable since most of these genera survived through the Lower Permian—or that they were barred from the region by climatic obstacles. The genera *Calamites, Neuropteris* and *Cordaites,* and probably *Pecopteris,* were present in the Grand Canyon region in early Supai time, and they may be collected near the base of the Supai not far east of the Yaki trail. They are also present in the Lower Permian along the Rocky Mountains in Colorado and New Mexico. It is, accordingly, evident that changes in the environment as well as a relatively late date, not earlier than the Upper Rothliegende, for the Hermit flora are responsible for the complete absence, so far as yet known, of these Pennsylvanian genera from the Hermit shale. It is significant that no pre-Permian species is found in the present Hermit collections.

In passing it may be noted that in eastern North America we find the Lower Permian, about 1,300 feet thick in the Appalachian trough, marked by a moderately moist climate under which thick red beds, denoting weather with relatively dry warm summers, were interspersed with numerous coal beds laid down in swamp environments and intercalated with fresh-water limestones. Here the flora is composed overwhelmingly of species inherited from the Pennsylvanian, or forms obviously descended from Pennsylvanian ancestors indigenous to the same basin. The species characteristic of the "cosmopolitan" Permian are evidently immigrant stragglers and relatively few at best.

Farther west, in the Mid-Continent region, the number of Pennsylvanian survivors in the Permian is very much smaller. Permian conifers become more prominent in the flora, and *Gigantopteris,* an eastern Asiatic genus, is abundant, together with *Tæniopteris,* which is rare in the Appalachian trough. Salt and gypsum deposits succeed the lowest Permian plant-bearing beds of the Mid-Continent region.

With the increasing aridity of this part of the continent the flora becomes greatly reduced, with rapid disappearance of Pennsylvanian species belonging to the groups already mentioned, while the plant association becomes not only more exclusively Permian, but it appears to develop provincial aspects in response to environmental differences, chief among which are those of climate. Accordingly, in the Wellington formation of Kansas the representation of *Pecopteris* and *Neuropteris* is very slender, but *Tæniopteris* and *Callipteris* are abundant in association with a peculiar genus, *Glenopteris,* which is probably related to *Supaia* in the Hermit flora. The region occupied by the Wellington formation in Kansas had experienced both aridity and alkalinity, more or less fatally inhospitable to the Pennsylvanian types. However, the Wellington plant-bearing beds are not red; they contain more or less carbonaceous matter, indicating an interval of less aridity, or at least of shorter dry seasons. *Tæniopteris,* which is relatively rare in the Lower Permian floras of the humid regions, is plentiful in the Wellington shales and in the Upper Permian of most parts of the world.

Great regions of salt deposition, distributed through hundreds of feet, separate the Grand Canyon region from the Great Plains. Some of this saline deposition took place between the time of the Lower Permian floras of the Appalachian and Mid-Continent regions or the early Supai flora on the one hand, and the Hermit shale on the other. There is little room for doubt that adversity of climate was responsible for the exclusion of Permian species of some of the Pennsylvanian genera from the Hermit, notwithstanding the apparently late date of the latter in the Lower Permian.

A rather distinct indication of a climate unfavorable both to the former indigenous plant life and to the plant life of regions of denser plant population is found in the relatively small size of the Hermit plants themselves. Nearly all the herbaceous forms are low and small. Among the impressions or collapsed molds of flattened stems and trunks of trees none has yet been found to exceed 12 cm. in diameter.

The herbaceous flora contains *Callipteris* and *Tæniopteris* (the latter much more abundant than the former), which are found in other parts of the world, but the greater volume of the herbaceous plant life is composed of previously unknown species of *Supaia* and

"Brongniartites?" both of which, though probably derived from late developments of *Callipteris,* find their closest relatives in the Upper Permian of Eurasia and Gondwana land, as already stated. These two genera, being adapted to the environment, appear to have largely monopolized the habitable ground along the Hermit arroyos.

Further circumstantial indications of unfavorableness of climate and in particular of long dry seasons are found in the large number, including new kinds, of coniferous trees. In early days as well as at present in most regions of the world, the conifers occupied areas that, on account of marked seasonal severity, especially periods of drought, were less endurable to other classes of vegetation. The genus *Walchia,* which appears to have had its origin in the effort of a moist-climate flora to withstand increasingly dry summers, is most at home in regions of red beds deposition and possibly more or less alkaline soils, and even in basins of highly concentrated salt waters whose evaporation left extensive deposits of gypsum and salt. The genus is rather typically a "red bed" genus, and it becomes relatively prominent as proof of aridity is more abundant, with concomitant disappearance of forms less resistant to drought. Not only is *Walchia* represented rather abundantly by several species in the Hermit flora, but *Voltzia, Ullmania,* and two or three other genera of conifers are also present.

Direct evidence as to climate is afforded by the distinctly xerophytic characters of the flora. As seen in the photographs, nearly all the herbaceous plants had very thick, leathery leaves, many of which were provided with dense villous or scaly coverings. Most of the species of *Supaia* had rigid pinnules. "Fuzziness" is prominent. Some of the leaves of *Supaia* and the species of *Sphenophyllum* commonly present, which was probably amphibious, seem to have had the habit of rolling back into longitudinal quills, apparently for protection against loss of moisture, like the fronds of *Pellaea* now living in the Canyon. Rarely is it possible to discern the nervation of most of the fronds unless maceration was advanced, so deeply immersed were the nerves and so dense the covering.

Laciniation or dissection of the leaf is minimized. Simplicity is the rule. The leaves of *Supaia,* which may have grown in tufts from root stocks, were low, with two simply pinnate divisions above a bifurcation, below which the reduced pinnules may have extended to the base of the very short petiole. In some of the fronds of this genus, and in most of the fronds tentatively referred to *Brongniartites,* the pinnules sat oblique to the rachis, and, in certain species, were ventrally concave as though to catch precipitation and pour it into the gutter formed by the ventrad flaring wide decurring laminæ bordering the rachis. The stems and axes of all the fern-like plants

are thickly clothed with scales or spines (Plate 33, fig. 3), which in some species are scattered even along the median nerves. The leaves of several forms are provided here and there with spicules along the borders. Petioles are short and scaly. Even in *Tæniopteris* the axis of the leaf is rugose. Thickening of the lamina is prominent in *Callipteris conferta.*

Another significant feature of the Hermit fossils as viewed from the climatic standpoint is the complete absence of all organic matter remaining from the plant substance itself. No carbonaceous residue has been seen in any case. Only in thin local lenses or pockets of sand, limited generally to a few inches in extent, has a gray matrix been found about the plants, and even here the organic matter itself is entirely wanting. It is evident, therefore, that conditions were extremely favorable not only for the full oxidation of the iron, but for the destructive oxidation of all the organic matter.

Further, the underlying "Esplanade sandstone" appears not to have been cemented at the time of early Hermit deposition. Attention has already been called to the lack of Supai pebbles in the Hermit channels. It is fairly evident that the Esplanade was porous at that time, offering good drainage to the uncemented, non-argillaceous Hermit sediments, which, accordingly, were adequately aerated, even where rapidly deposited. Had there been a water table in the Esplanade hollows, such as would have been essential to the maintenance of a permanent water level at or close beneath the surface of the Hermit, we should have found not only a less complete oxidation of the iron, but also the carbonized remnants of portions of the carbohydrate plant matters in some of the rapidly accumulated deposits. There should have been sufficient moisture in the latter to preserve some at least of the more resistant plant products from complete decomposition. Lack of all traces of carbonaceous residues can not be due to slowness of sedimentation; some of the beds, as has already been described, were rapidly laid down, the plants being enveloped in an upright position. Yet no tissue of organic composition has been noted in any stem, branch, cone, or seed. The disappearance of such plant products as spore exines, seed envelopes and cuticles, which are ordinarily indestructible if buried in a moist habitat, is significant and confirms the lack of permanent saturation of the newly deposited sediments. The spaces in the sandstone, shales, or even the silty layers formerly occupied by the plants, are now either collapsed or filled by sand, silts, or soft brownish-red friable iron clay. Evidently no water cover retarded the decompositional processes long enough to permit burial of the organic debris beyond reach of sufficient oxygen for the total conversion of the organic matter into CO_2 and water.

II. COMPOSITION, AGE, AND RELATIONS OF THE HERMIT FLORA

COMPOSITION

The Hermit flora as now known comprises 35 species of fossil plants, which are here described with three additional fossil forms, probably of animal origin. Several insect wings have been found,[1] together with numerous footprints of vertebrates, as has already been mentioned. The present status of the flora is, however, merely momentary, for the number of species will assuredly be greatly increased as the result of further search, with the probable discovery of types now known in other continents, as well, doubtless, as new forms of evolutionary and geographical interest.

Following is the list of fossil species, here described, in systematic arrangement:

PLANTS

Thallophyta
- *Algæ*
  - *Cyanophyceæ ?*
    - *Rivularites*
      - *R. permiensis* n. sp.

Arthrophyta
- *Sphenophyllales*
  - *Sphenophyllum*
    - *S. gilmorei* n. sp.

Pteridospermaphyta
- *Callipteridales*
  - *Callipterideæ*
    - *Callipteris*
      - *C. conferta* (Sternberg) Brongnart
      - *C. arizonæ* n. sp.
      - *C. raymondi* Zeiller
      - *C. ?* sp.
  - *Supaiaceæ*
    - *Supaia* n. g.
      - *S. thinnfeldioides* n. sp.
      - *S. rigida* n. sp.
      - *S. sturdevantii* n. sp.
      - *S. merriami* n. sp.
      - *S. compacta*
      - *S. anomala* n. sp.
      - *S. linearifolia* n. sp.
      - *S. breviloba* n. sp.
      - *S. subgoepperti* n. sp.
      - *S.* sp.
      - *S.* sp. indet.
      - *S. ?* sp.

[1] See *Typus whitei* Carpenter, pl. 51, fig. 1.

Pteridospermaphyta—Cont.
Supaiaceæ—Cont.
Brongniartites
B. ? yakiensis n. sp.
B. ? aliena n. sp.
Yakia, n. g.
Yakia heterophylla n. sp.
Neuropteridium ? sp.
Tæniopterideæ
Tæniopteris
T. cf. *eckhardti* Kurtze
T. angelica n. sp.
T. coriacea Goeppert.
Ginkgophyta
pro-Ginkgoales
Psygmophyllum
Ps. sp.
Coniferophyta
Araucariales
Araucariaceæ
Walchia
W. piniformis (Schloth.) Brongnart
W. dawsoni n. sp.
W. gracillima n. sp.
W. hypnoides Brongnart ?
Ullmannia
U. frumentaria (Schloth.) Goeppert
Voltzia
V. dentiloba n. sp.
V. sp.
V. ? sp.
Taxales
Paleotaxaceæ
Paleotaxites n. g.
P. præcursor n. sp.
Taxites
T. ? sp.
Pinales?
Brachyphyllum
B. arizonicum n. sp.
B. tenue n. sp.
Pagiophyllum
P. dubium n. sp.
Fruits of uncertain affinities (twigs and fructifications)
Cyclocarpon
C. angelicum n. sp.
C. sp.
Carpolithus
C. sp.
Eltovaria n. g.
E. bursiformis n. sp.
Gymnospermous ament

ANIMALS

Insecta
Megasecoptera
Protodonata
Typus
T. whitei Carpenter [1]

[1] F. M. Carpenter, Psyche, vol. 35, No. 3, page 188, text-fig. 1, pl. 5, 1928. *Typus gilmorei* was earlier described by the same author from the Hermit shale.

Vermes ?
- *Scoyenia* n. g.
  - *S. gracilis* n. sp.
- *Walpia* n. g.
  - *W. hermitensis* n. sp.

Crustacea
- *Euripteridæ ?*
  - *Hastimima ?*
    - *H.* sp.

TWO FLORAL PROVINCES REPRESENTED

Two important features of the composition of the Hermit flora are strikingly apparent. First, it is largely composed of forms previously unknown, due largely, at least, to the fact that the flora is younger than the Lower Permian floras described from other regions of North America. In fact, less than half the species have previously been known from other Permian regions and formations. Second, the flora presents a unique aggregate, one part of which belongs to and is characteristic of the western European or cosmopolitan Permian flora, while the other part is connected with the Gondwana flora of Eurasia and the Southern Hemisphere.

The first floral element represents or is plainly descended from the floras of the Lower Permian in the basins east of the Rocky Mountains in Colorado, New Mexico, Texas, Oklahoma, Kansas, the Appalachian Trough and in western Europe. Of the other or oriental element a small part is specifically bound to the Uralian region. The remaining relatively large portion is so closely connected with a peculiar floral group, not found in the cosmopolitan Permian flora but characteristic of the late Lower and the Upper Permian of the Uralo-central Asian region, with relatives and successors in the latest Permian and in the Triassic or supposed Rhetic formations in the regions of Permian glaciation—i. e., the so-called Gondwana province—as to leave no room for doubt as to their common origin.

The province of the Gondwana flora embraces portions of India, Australia, South Africa and southern South America, with an indicated occurrence in Antarctica. The Hermit relatives in India and the southern continents are found in the floras that followed or grew out of the *Gangamopteris* flora, or so-called "lower Glossopteris flora" (Lower Gondwana flora) that immediately succeeded the great Permian ice sheets in this region and occupied the same areas. The Gondwana province was marked by distinctive floras, with, at times, distinctive climates, until the Rhetic, when the upper Gondwana flora became merged in the world-wide Jurassic flora, with concomitant disappearance of major evidence of climatic or geographic isolation.

The cosmopolitan and oriental elements of the Hermit flora will be more fully defined in the discussion of the "age and origin of the flora."

In the Hermit flora the herbaceous plants, including the Pteridosperms on the one hand and the shrubby or arborescent gymnosperms on the other, are fairly well balanced. No forms recognized by the writer as ferns are present in the collections now in hand. The genus *Callipteris,* primary representative of the cosmopolitan plant association, was long ago shown by Grand'Eury [1] to have borne seeds *(Carpolithus).* The reference of *Supaia* and *"Brongniartites,"* of Eurasian connections, to the "cycadofilices" is based on (*a*) their apparently close relations both to *Callipteris* and to *Gigantopteris* (Asiatic), which almost certainly was seed-bearing; and (*b*) the absence of all indications of fern types of fructification.[2] It is not impossible that ferns—more likely related to the Marratiaceæ—will be found in the beds, for they were then living in other regions. *Scolecopteris,* in particular, of western Europe, is therefore to be expected. *Tæniopteris,* which has never disclosed demonstrable fructification in any Paleozoic species, is supposed by certain authors to be related to the Neuropterids. It is, I believe, a true Pteridosperm. In fact, I am inclined to think that *Eltovaria,* a somewhat doubtful genus, is the fruit either of *Tæniopteris* or more probably of the group represented by *Supaia.*[3]

Yakia is of unknown affinities. By its aspect it seems connected with *Callipteris* (cf. *C. strigosa*), and I am inclined to regard it as closest to this genus. If the fragments, apparently bearing appendages interpreted as cupules or sporangia, belong to *Yakia,* as I am disposed to believe, the genus is probably Pteridospermic. Uncertainty remains as to the specific reference of the fertile fragments. On the other hand, *Yakia* may be a gymnosperm.

The apparent absence from the Hermit shale of the entire Calamarian group is probably due to seasons of too great aridity; surely, if the environment were not too dry, it should have some representative such as *Schizoneura, Phyllotheca* or *Calamites* in this flora. To the same cause, if not to a too late age of the flora, is almost certainly due the absence of *Neuropteris, Alethopteris, Linopteris* and *Odontopteris,* Pennsylvanian genera, one or all of which are present in most of the early Permian basins, including those of central and eastern America, that were inhabited by the cosmopolitan flora. Pecopterids of the tree-fern (*Psaronius*) group may later be discovered and so may some Permian species of *Spheno-*

[1] C. Grand'Eury, Comptes Rendus, vol. 143, 1906, page 664.

[2] Mention should be made of the description of sori of Marrattiaceous aspect on the upper surface of a species, ***Thinnfeldia lancifolia,*** of supposed latest Permian (lower Beaufort) age in South Africa. See A. B. Walkom, ***Mesozoic Floras of Queensland,*** pt. 1 (cont'd): Queensland Geol. Survey Pub. No. 257, 1917, page 21, pl. 3, f. 3.

[3] The seed seen on the specimen of ***Brongniartites ? yakiensis,*** illustrated in Plate 28, figure 1, though seeming to be attached to the rachis at the base of the mid-nerve of a pinnule, is not definitely shown to be in organic union with the plant.

pteris, though I regard the presence of the latter as highly improbable. *Cladophlebis* may well be present, if the climate was not too dry.

Failure to find any leaves of *Cordaites,* or *Nœggerathiopsis,* its Eurasian equivalent, is notable. Some, at least, of the *Cordaites* group were non-swamp plants. Possibly slight alkalinity of the soil, such as may be inferred from the presence of the molds of salt crystals, like those shown in Plate 33, figure 2, at certain points in the shales, may have been more responsible than a late age for the absence not only of *Cordaites,* but of some of the other above-mentioned Pennsylvanian genera that are usually sparsely represented in the early Permian floras.

In addition to *Walchia,* represented by three species, and *Ullmannia* and *Voltzia,* each with one species, all belonging or supposed to belong to the Araucarian stock and all having identical or closely related species in the cosmopolitan Permian floras, we find several forms apparently related more closely to the Yew family and that are more suggestive of a Mesozoic than of any known Paleozoic flora. These include, in particular, the species described under *Paleotaxites, Brachyphyllum* and *Pagiophyllum.* The presence of Taxalean fruits on one of the species is especially notable.

AGE AND ORIGIN OF THE FLORA

The examination of both the sources and the age of the Hermit flora is complicated by the mingling of eastern and western elements and lack of agreement as to the relative ages and correlations of the terranes in the two provinces.

No species found anywhere in beds unquestionably as old as the Stephanian (upper Pennsylvanian) has yet been found in the Hermit shale. *Walchia piniformis,* a plant of wide vertical range, appears in fact to be the only species in the list that occurs in beds for which a pre-Permian age is sometimes contended. All the species of *Walchia* are European or very closely related to species in the Lower and basal Upper Permian of Europe. One species, *W. gracillima,* seems identical with a species found near the base of the Zechstein in the Ural region. The presence in the Hermit flora of *Voltzia* and *Ullmannia,* which are more characteristic of the Upper Permian, though *Ullmannia* is reported from the upper part of the Lower Permian, points to a stage not below late Lower Permian, or Upper Rothliegende, in regions where that term is used. The absence of the Neuropterid genera, though possibly due to climatic factors, accords with a place above both the lower and the middle Rothliegende, if not as high as the Zechstein. A reference to so high a stage finds circumstantial support in the presence of Neuropterids about 800 feet below the Hermit, near the base of the Supai, which, also Permian

in age, is separated from the Hermit by a minor erosional unconformity. Certainly, the Neuropterid genera were not excluded from this region in early Permian time.

It should be noted that *Ullmannia*[1] is present also in the upper Gondwana Raniganj group, probably of Upper Permian age, in the Gondwana province, while *Voltzia* is found also in the Triassic of Europe. It is generally indicative of Upper Permian or later age, though, like *Ullmannia,* it is rare in the upper part of the Lower Permian.

Callipteris conferta is a polymorphous species, in which, however, the polymorphy is more noticeable in the later forms—i.e., in the time sequence—than in a single plant or a single plant association. This may be seen by comparing the forms in the Lower Rothliegende with those in the Upper Rothliegende, and, especially, in the Zechstein, where sympodial dichotomy is clearly shown, accompanied by great variation in the pinnule, particularly near the apex of the frond. The form with relatively large compound fronds in the Hermit may be regarded as typical or normal if we disregard its xerophytic characters. The normal phase is seen in the Lower Permian (both Lower and Upper Rothliegende). Pinna sympodially dichotomous and provided with broad pinnules suggesting, or even referred by error, as I hold, by some authors to *Odontopteris* are especially seen in the Zechstein Angara flora. To these *Supaia* is unmistakably closely related. Among the European plants the nearest approach to *Callipteris arizonæ* is found in the fronds from the Upper Rothliegende of Bohemia and the Lodeve Zechstein, illustrated by Goeppert[2] and Zeiller[3] as *Callipteris affinis* and *C.* cf. *affinis,* respectively.

The Arizona plant which I identify as *Callipteris raymondi* appears to agree with that species, though the pinnules are slightly larger than those from the basin of Blanzy and Creusot in France, where the containing beds, at Charmoy, were classed by Zeiller as upper Autunian.

The three species of *Tæniopteris* in the Hermit belong to the group with straight, mostly simple, moderately oblique nerves which is common in the upper part of the Lower Permian and in the Upper Permian. The group extends with considerable diversity into the upper Gondwana floras of the southern (Gondwana) province. In Europe *Tæniopteris coriacea* belongs in the Upper Rothliegende

[1] As mentioned in the description, some of the specimens referred by me to *Ullmannia* seem to have borne forked leaves, possibly in specific agreement with the specimen from the lower Gondwana Karharbari described by Seward (Mem. Geol. Survey India: Paleontol. Indica, n. s., vol. VII, No. 1, 1920, page 12, pl. II, fig. 20-25*a*) as *Buriadica.*

[2] H. R. Goeppert, Foss. Fl. Perm. Form., 1864, page 105, pl. XII, fig. 1.

[3] R. Zeiller, Bull. Mus. d'Hist. Nat. de Marseille, vol. I, No. 2, 1898, page 27, pl. III, fig. 4.

and lower Zechstein; *T. eckhardti* in the copper shales of the base of the Zechstein. A species extremely close to *Tæniopteris angelica* is illustrated by Halle from the Upper Shihotse beds of central Shansi in China, where also are found forms close to *T. coriacea,* which is frequent in the Wellington formation of Kansas. However, close allies of *T. angelica* and *T. eckhardti* occur in the Lower Shihotse.

There is but one known species to which *Sphenophyllum gilmorei,* with its large narrow, spatulate, entire or slightly erose leaves can be compared. That is *Sphenophyllum stouckenbergi* Schmalhausen, from the post-Artinsk of the west slope of the Ural Mountains.[1] The latter species has less elongated and smaller leaves, but it is so close to our plant as to leave no doubt as to its common origin and extremely close relationship. In fact, the differences are perhaps no greater than would be expected in plants so widely separated geographically, with reaction to slightly different environments in transit. According to the paleobotanical standards of western Europe, the Artinsk is somewhat above the base of the Lower Permian, its upper limit being placed in the Saxonian. Since *Sphenophyllum stouckenbergi* belongs higher than the Artinsk, the question as to whether the migration of *Sphenophyllum gilmorei* was from the Ural region to Arizona, or *vice versa*—ignoring its possible origin in some intermediate region—depends on whether the Hermit shale is the older deposit. In any case, the migration was assuredly by the Pacific route. I have little doubt that this unique type of *Sphenophyllum* crossed from Asia to America, or oppositely, by the same north Pacific route as that followed in earlier Permian time by *Gigantopteris.*

In *Supaia,* represented by eight species, and in the two species referred with some doubt to *Brongniartites,* we have an important floral element whose closest relations and principal distribution are found in Eurasia and the Gondwana province. It is probably derived from the *Callipteris* stock, which in the Upper Permian has common features in the development of the frond. The rather wide range of forms found in what I term the *Supaia* group meets its congeners and even near-counterparts, not in the Lower Permian of western Europe, though trace of several Uralian forms is rarely found there as the result of westward migration, but in the topmost Lower Permian and the lower part of the Upper Permian of the Uralian region and central Asia, and in the province of the Gondwana floras. The group is characterized by once bifurcated fronds, in which the strongly

[1] Mém. Comite Géol., vol. II, No. 4, 1887, page 5, pl. II, figs. 1-12.

Sphenophyllum thonii, of the "cosmopolitan" Permian, is represented by forms considered identical by some paleobotanists and certainly related to the French species, in both the Lower Shihotse series of Shansi and in the Permian of the Ural region.

unsymmetrical divisions, facing each other *vis a vis,* are simply pinnate or pinnatifid, with the inner pinnules gradually reduced to shrunken lobes in passing downward to the bifurcation of the frond; while the outer pinnules, which are much longer, also decrease in length in passing downward so as to narrow the limb of the frond, decurrent-wise, to a vanishing point a short distance below the dichotomy of the rachis. The lamina of the pinnules is characteristically decurrent and commonly inflated-eared in the base of each pinnule, and the nervation ranges from Alethopteroid in the lanciform pinnules, which may be linear, to Neuropteroid in some of the broader pinnules—especially the oblong forms, rounded at the top, approaching *Brongniartites.* In the Gondwana floras a few forms in which the two equal divisions are bipinnate have previously been included, possibly rightly, in the same genus with the species with simply pinnate divisions.

The *Supaia* group is represented by *Danæopsis hughesi* in the lower Gondwana flora, where it occurs in the Panchet group at the top of the lower (Permian) Gondwanas and in the transitional beds of the South Rewah coal field, classed as middle Gondwana, also Permian, in India. It is present in the Ipswich beds, now generally regarded as Lower Triassic, in Queensland, and in the lower Beaufort beds of South Africa, of uppermost Permian age, though regarded by some palæontologists as Lower Triassic or even Rhetic. It is reported to be present both in the lower Zechstein, Permian, of the Uralian region,[1] and in the middle or upper Lower Permian of Shensi in China.[2] The frond of *Danæopsis hughesi* is once dichotomous in the lower part, the equal divisions being unsymmetrical, and it has a Neuropteroid apex and semi-Neuropteroid nervation in obtusely rounded pinnules. It is now well recognized that its reference to the cosmopolitan Mesozoic genus *Danæopsis* is on all accounts erroneous.

Forms with apparently non-forked, simply pinnate fronds from both the Lower and the Upper Shihotse beds of central Shansi, have, with little regard to the characteristic dichotomy of the pinnatifid frond of the Gondwana plant, been generically grouped with *Danæopsis hughesi* by Halle,[3] who erroneously refers them all to the genus *Protoblechnum,* known only in the upper Pottsville of Ohio, to which genus he also provisionally refers the plants from the Wellington shales of Kansas described by Sellards[4] as *Glenopteris,* in which

[1] M. D. Zalessky, Bull. Soc. Oural. d. Sci. Nat., Ekaterinburg, vol. XXXIII, 1913, page 14, pl. 1, figs. 2-6.

[2] Fr. Krasser, Denksch. d. K. Akad. Wiss., Wien, Math.-Nat. Kl., vol. LXX, 1900, page 145, pl. II, fig. 4.

[3] T. G. Halle, Pal. Sinica, ser. A, vol. II, fasc. 1, 1927, page 131.

[4] E. H. Sellards, Kansas Univ. Quart., IX, 1900, page 180.

dichotomy of the frond is as yet unknown. There appears to be good reason for the reference of the Shansi plant to *Glenopteris.* Both have simply pinnate or simply pinnatifid fronds with thick and slightly expanded bases where attached to the parent axis.

As already indicated, I view the inclusion in a single form genus of a group having uniformly once-bifurcated fronds and another group with invariably simple fronds, as in *Protoblechnum* and *Glenopteris,* as untenable. Therefore, the genus *Supaia* is in later pages proposed to cover the group, including *Danæopsis hughesi,* with dichotomous simple or simply pinnatifid fronds, in which the conspicuously asymmetrical divisions form a limb that narrows decurrently for some distance below the bifurcation. Variations in the forms of the apices of the fronds and in the pinnules of the Hermit species of the genus are illustrated somewhat fully in this report.

The form from the Lower Permian of the Hei-Shan coal field in Shantung, described by Yabe and Oishi[1] as *Protoblechnum hallei,* seems referable to *Glenopteris* and should be recorded as *Glenopteris hallei* (Yabe and Oishi). The incomplete pinnæ from the Chang Chiu coal fields in the same province, identified by the same authors[2] as *Protoblechnum wongi* Halle, also should, if the frond is simple, be transferred to *Glenopteris.*

The genus *Supaia* is also represented by a group of forms, generally with lanciform pinnules and Alethopteroid nervation, in the Gondwana province referred by various authors to *Thinnfeldia.* *Thinnfeldia odontopteroides* (Morris) Feistmantel, apparently the best-known, the oldest, and the most widespread species of the group, is described as embracing not only small dichotomous fronds with simply pinnate divisions, closely approximating some of the Arizona plants, but forms with larger fronds, already referred to, that are bipinnate, and in which the ultimate pinnæ are developed, with diminution below the bifurcation of the main rachis, after the plan of the simple fronds. The generic differentiation of these dichotomous species of *Thinnfeldia* from the typical *Thinnfeldia* with simple fronds in the Rhetic of Europe is obvious, on which account Gothan established the genus *Dicroïdium*[3] for the Gondwana province plants. However, the examination of the species found at different stages of the uppermost Permian and of the Triassic of this province, and referred by paleobotanists to *Thinnfeldia* or *Dicroïdium,* shows that nearly all of them are characterized by simply pinnate dichotomous fronds with Alethopteroid, sometimes elongated lanci-

[1] H. Yabe and S. Oishi, Japanese Journal Geol. and Geogr., Trans. & Abstr., vol. VI, No. 1-2, 1928, page 17, pl. v, fig. 1-2.
[2] Loc. cit., page 61, pl. xii, fig. 1-4.
[3] W. Gothan, Abhandl. Naturh. Gesell. Nürnberg, vol. XIX, 1912, No. 3, page 75.

form pinnules with Alethopteroid nervation, verging into a Neuropteroid form. This group is, to my mind, generically distinct from the bipinnate plant with quadrate, ovate, or rounded pinnules and disstinctly Odontopteroid nervation, which unfortunately is made the type of Gothan's *Dicroïdium.* Hence, my preliminary reference [1] of the Hermit plants to *Dicroïdium* was an error. Further, I have felt obliged to include nearly all the Gondwana species referred to the latter genus, together with *Danœopsis hughesi,* in the genus *Supaia,* whose type is in the Hermit flora.[2]

The dichotomous, simply pinnate fronds referable to *Supaia* but included by authors with *Thinnfeldia odontopteroides* are found in the "transitional beds" (Parsora, near Beli) of Upper Permian age in the South Rewah fields and in the Panchet group, also Upper Permian, in India. Figured forms referable to the *Supaia* are present also in the Hawksbury and Wianamatta beds in New South Wales, and the Ipswich beds, also of supposed Lower Triassic age, in Queensland; and in beds of the same age, whatever it may be, in the Jerusalem basin in Tasmania.

The approach of the *Supaia* forms with tapering acute leaves to some of the lanciform-pinnuled species described as *Thinnfeldia* from beds regarded as Upper Triassic in South Africa and Rhetic in Argentina is especially close, and affords a reasonably sound basis for the conclusion that these are derived from the same stock as the Arizona plants, which appear generically inseparable. The Hermit plants probably are older than any of the Gondwana representatives of the genus. If so, the question arises whether *Supaia* was from late Lower Permian to the Rhetic in migrating from Arizona to Argentina.

As already indicated, *Danœopsis hughesi,* which I regard as congeneric with *Supaia,* is reported in the lower part of the Zechstein of the Ural region, and is possibly present in beds of highest Lower

[1] *The Flora of the Hermit Shale in the Grand Canyon, Arizona,* Proc. Nat. Acad. Sci., vol. 13, No. 8, Aug., 1927; *Study of the Fossil Floras in the Grand Canyon, Arizona,* Carnegie Inst. Wash. Year Books No. 26, (1926-27) pages 366-369 and No. 27 (1927-28), 1928, pages 389, 390.

[2] Note: That the close resemblance in form of frond development in two of the species from beds supposed to be of uppermost Permian or Triassic age in South Africa to the Arizona plants is merely accidental is suggested by the presence of sporangia of a Marrattiaceous type described as on the upper surface of the two species. In no other region is any type of sporangium found definitely correlated with the type of frond exemplified in the *Supaia* group.

On the other hand, the very close relation of *Supaia* to certain Callipterid species with dichotomous fronds from the Zechstein of the Urals and from Lodeve, illustrated by Morris, Fisher De Waldheim, Kutorga, Goeppert, Zeiller and Zalessky as *Callipteris* or *Odontopteris,* is shown not only in the habit of development of the pinnæ, but also by the bifurcated type of frond, especially as it is seen in plants from the Uralian Zechstein and the upper Rothliegende of Ottendorf, in Bohemia, described by Goeppert (Foss. Fl. Perm. Form., 1864, page 105, pl. 12, fig. 1) as *Callipteris affinis,* with which Zeiller (Bull. Mus. d'Hist. Nat. de Marseille, vol. 1, No. 2, 1898, pl. 3, fig. 4) compares a frond from Lodeve in Alsace. The latter, though partially bipinnate, agrees in general form and mode of development with *Supaia.* It is obviously close also to *Callipteris arizonœ.*

Permian in China, though some, at least, of the specimens from Shansi referred to that species or to *Protoblechnum* appear to belong to *Glenopteris*.

Brongniartites is known only near the base of the Zechstein in the Ural region and probably in the Hermit shale.

Whether the stock represented by the Hermit *Supaia* and *"Brongniartites?"* migrated from America to Asia, as seems quite possible, or from an undetermined Asiatic center of origin to America and to India, whence it spread to South Africa and southern South America in very late Permian, to give rise to the austral Triassic forms, remains to be proved, but it is important to note that *Supaia* was present in the Indian portion of the Gondwana province and probably also in the African in late Permian time.

Better as well as less remote criteria for the age correlation of the Hermit shale are to be found in the northern Russian and central Asian areas. In the lower Zechstein of Pechora, northeastern Russia, we find species of *Gangamopteris, Glossopteris, Nœggerathiopsis* and *Schizoneura* characteristic of the lower Gondwana flora, together with *Supaia (Danæopsis) hughesi,* mingled with *Psygmophyllum, Callipteris* and other Permian genera of the northern hemisphere. *Rhipidopsis* and other Gondwana genera of very wide distribution also are present. The combined evidence of vertebrates, mollusks and plants shows the containing beds to be of lower Zechstein (lower Upper Permian) age. In the Kuznetsk basin, of southwestern Siberia, and in nearby regions of Mongolia, also, the lower Gondwana flora is well represented, again with some mingled European genera in beds of long debated but probably later Lower Permian or early Upper Permian age.

The fact that these representatives of the *Gangamopteris* flora, which followed the ice sheets and which is regarded by many palæontologists as dating back to the beginning of the Permian, or possibly to the Pennsylvanian, as some argue, seem to have made their first appearance in the northern world at the beginning of the Upper Permian is interpreted as indicating that sea barriers had excluded them from the regions north of Tethys Straits until that time. On the other hand, the conclusion urged by Schuchert [1] is that the *Gangamopteris* flora and the ice sheets, with which its origin seems associated, had their beginning near the middle of Permian time, i. e., not long before the migration of the plants into the Uralian region and as far as the Arctic slope of northeastern Russia.

If this conclusion is valid, no considerable time may have elapsed between the genesis of the *Gangamopteris* flora in the regions of Permian glaciation and the appearance of the representatives of that

[1] Charles Schuchert, Bull. Geol. Soc. Amer., vol. XXIX, 1928 (1929) page 851.

flora in central Asia and northeastern Russia. Further, if the Hermit is not of very late Lower Permian age, the *Supaia* group may have originated in America and migrated thence to central Asia and the Gondwana province.

Forms approaching most closely the *Supaia* species with obtuse or even rounded pinnules and with semi-Neuropteroid nervation are illustrated by Zalessky in his atlas of the Permian plants of the Uralian border of Angara ("Angaride").[1] Here we find plant associations in beds of lower Upper Permian (Zechstein) age, in which *Supaia hughesi* and species of *Gangamopteris, Nœggerathiopsis* and *Phyllotheca,* the three latter genera being characteristic of the lower Gondwana, mingle with *Callipteris, Sphenopteris, Pecopteris, Calamites, Dicranophyllum, Ullmannia* and *Walchia.* In this flora, which includes large-pinnuled and sympodially forked Callipterids, some of which are so Odontopteroid in facies as to be described as *Odontopteris,* we find *Brongniartites salicifolius* (Fisher) Zalessky, which, so far as illustrated, can hardly be regarded other than as congeneric with *Brongniartites ? yakiensis,* to which it appears very closely related specifically. It is most unfortunate that the text of Zalessky's flora has not been published, so that more ample criteria for the systematic comparisons might be available.

As already noted, a gymnosperm, apparently identical with my *Walchia gracillima,* is figured by Zalessky from the Artinsk as *W. hypnoides,* while among the illustrated fragments of large bifurcating pinnæ, with broad, rounded Alethopteroid or even Neuropteroid pinnules from the Zechstein, several specimens strongly resemble *Brongniartites (?) aliena* and *Supaia oblonga.*

No trace of a Gondwana flora or of the *Supaia* group, in particular, has been found in the Lower Permian flora of China as described by Halle[2] from the Lower Shihotse series of central Shansi, which contains *Gigantopteris* as well as *Tæniopteris* and Permian phases of many Cosmopolitan genera. This accords with the view held by Schuchert that the Permian glaciation, the Talchir boulder beds, and the lower Gondwana (*Gangamopteris*) flora find their place near the middle of Permian time.

In the Upper Shihotse series, on the other hand, which is regarded by Halle as presenting "no evidence that it extends above the middle of the Permian—it may even fall entirely within the Lower Permian," and which is correlated by Grabau as "Middle or early Upper Permian," Halle finds representatives of *Asterophyllites, Sphenopteris, Pecopteris* and *Odontopteris,* along with *Gigantopteris, Tæniopteris,*

[1] M. D. Zalessky, *Flore Permienne des limites ouralennes de l'Angaride,* Atlas, Mém. Comt. Géol., n. s., No. 176, 1927. See plates IV, V, X, XI, XII and XXXIX.

[2] T. G. Halle, Paleontologia Sinica, Ser. A., vol. II, Fasc. 1, *Paleozoic Plants from Central Shansi, Peking,* 1927.

Rhipidopsis, Cordaites, Plagiozamites, Psygmophyllum, Neuropteridium, and a plant referable to Sellard's *Glenopteris* from the Wellington of Kansas. Apparently no demonstrated representative of the *Supaia* group is present, though *Glenopteris,* very likely a *Callipteris* derivative, is probably most nearly related to *Supaia.* Agreeing with Halle, I can not view the Upper Shihotse series as Upper Permian.

A single specimen in the Hermit collection is perhaps safely regarded either as *Psygmophyllum* or *Rhipidopsis. Psygmophyllum* occurs in the Artinsk and ranges up into the lower Zechstein of the Ural region. Forms most comparable to ours occur in the lower horizons. *Rhipidopsis,* which somewhat resembles *Psygmophyllum* and which appears to be at home and rather widespread in the Upper Permian of Petschora, Russia, and the Uralian Angaride, occurs also in the Gondwana Upper Permian and is reported from beds in the Southern Hemisphere supposed to be Triassic in age.

CONCLUSIONS AS TO THE AGE OF THE HERMIT SHALE

As already noted, the Hermit flora, of which a relatively small number of species has been collected up to the present moment, does not afford so satisfactory a basis as is desirable for long-distance correlation. Comparatively few of its species are found in other regions. The determination of its age is further complicated by the mingling of the elements from the cosmopolitan Permian with Oriental elements from the Gondwana province and from the central Asiatic region of mingled eastern and western types in beds of uppermost Lower Permian and lower Upper Permian (Zechstein) age. On the other hand, the presence of the eastern and western elements in the Permian of Arizona, while requiring the examination of their distribution in two floral provinces, in which there were at times marked climatic differences, offers, at the same time, two series of criteria for use in correlation.

The comparison of the Hermit flora with the western European Permian floras shows that (*a*) by the distribution of its identical cosmopolitan species, (*b*) by the facies or stages of development of its elements congeneric and closely associated with cosmopolitan types, and (*c*) by the apparent absence of Lower Permian survivors of the Pennsylvanian flora, including especially the Cycadofilic genera, *Neuropteris, Odontopteris, Alethopteris* and *Linopteris,* it is to be correlated with beds not earlier than the upper Rothliegende, with a portion of which, probably in the upper part of that division, it is contemporaneous.

The evidence of the cosmopolitan Permian elements, therefore, supports the evidence of the stratigraphy—i.e., the presence of 800

feet of Permian redbeds beneath the Hermit shale and separated from it by a minor unconformity—in the assignment of the Hermit flora to a stage near the top of the Lower Permian. The presence of Permian species of identical Pennsylvanian genera in the Lower Permian of China, as well as in Texas, Oklahoma, Colorado and Kansas, establishes the probability that the exclusion of these Pennsylvanian genera from the Hermit shale of Arizona is not due wholly to climatic or other physical barriers. Mention may again be made of the fact that the lower part of the Supai in the Grand Canyon has yielded fragments of *Cordaites, Neuropteris* and *Calamites,* as well as *Tæniopteris* and *Walchia.* So far as known to me, no sea invasion interrupted the continuity of land plant life in this part of Arizona between lower Supai time and the end of Hermit time.

On the other hand, the examination of the Gondwana, the Ural, and the central Asiatic floras shows that the congeners with fronds of the type characterizing the *Supaia* group, are hardly known below the topmost stages of the Lower Permian and the Zechstein. The testimony of the *Sphenophyllum* is consistent with that of the Pteridosperms. The evidence of the Oriental or Eurasian group is, accordingly, nearly in agreement with that of the Cosmopolitan elements, the weight of the former being in favor of a stage slightly higher than that roughly indicated by the latter.

The facts (1) that the most prominent element, the *Supaia* group (including *"Brongniartites?"*) in the Hermit shale connects with a conspicuous and characteristic element of the latest Permian and the Triassic floras of the Gondwana province, with points of resemblance in the world-wide Rhetic flora, and (2) that some of the gymnosperms are relatively modern in facies, combine with the absence of the genera of Pennsylvanian range to give the Hermit flora as a whole a Mesozoic aspect that, at first glance, is deceptive regarding the true age of the Hermit shale. In short, the Hermit flora is precociously Zechstein—the result, probably, of the climatic factors in its environment.

The more arid climate of the Hermit in Arizona appears to be responsible for reduction in the size of the plants and greater simplicity, with simple dichotomy, of the fronds of the Cycadofilic (Pteridospermic) group, as well as for the distinctly xerophytic characters. It is presumably responsible for specific differences, and may account for the absence of older genera, but it should not seriously affect contemporaneity in other regions of the representatives of the genera or species present, especially in view of the then existing intercontinental land connections, both on the east and on the west.

The Hermit flora is the latest Paleozoic flora yet known in America. To this fact may be due not only its unlikeness to the other Permian floras of this continent, but the presence also of both Gondwana plants and plants of distinctly Mesozoic aspect. It remains to be seen whether Oriental elements are to be found in the Permian of other parts of America, and what will be the geographical as well as vertical distribution of the types. In view of the lateness of intercontinental land connections proved by this flora, it becomes not unlikely that other Gondwana or Eurasian types will be found, possibly in associations that will throw further light on the precise date of earliest Gondwana glaciation as well as on plant distribution, on climatic provinces, and on intercontinental relations.

In view of the presence in the Canyon wall, above the Hermit shale, of 500 feet of remarkably cross-bedded gray Coconino sandstone, possibly of eolian origin, in sharp contrast with the marine Kaibab, it is evident that the Kaibab limestone, which also is Permian, must stand high in the Permian scale if the Hermit belongs well up in the upper Rothliegende—the upper part of the Lower Permian, if the Permian be classified in two principal divisions. The Kaibab limestone itself, about 575 feet thick in the vicinity of Grand Canyon station, may represent an appreciable lapse of time. The lower division, about 75 feet in thickness, contains a gastropod fauna and throughout a large area may readily be segregated stratigraphically as well as palæontologically as a distinct map unit, for it is separated from the upper two-thirds of the formation by a thin zone of red and gray sands, probably derived from the sources of the Supai and Coconino sands, with which are interbedded travertines and conglomerates showing subaerial exposure and erosion. The upper or major portion of the Kaibab carries a varied fauna, including a representative of the trilobites, as well as large ammonoids and giant pelecypods, like *Allorisma.* Therefore, notwithstanding the absence of local evidence of unconformities between the Hermit and the contrasting Coconino, and the Coconino and the Kaibab, I am unable to view the Kaibab limestone as dating earlier than Upper Permian or Zechstein. If subsequent studies by the invertebrate palæontologist confirm this conclusion, while establishing the palæontological as well as stratigraphic relations of the Kaibab to the Guadaloupe group, we may, I believe, find the red and gray sandstones and gypsiferous marls above the great limestone series in west Texas to be contemporaneous as well as homotaxial with the gypsum and salt-bearing marls and sandstones of supposed latest Permian age in the central Germany and the Uralian regions.

III. DESCRIPTION OF THE HERMIT FLORA

THALLOPHYTA

ALGÆ

CYANOPHYCEÆ

***Rivularites* Fliche, 1905**

Bull. Soc. Sci. Nancy (3) vol. 6, p. 46

Rivularites permiensis D. W. n. sp.

PLATES 6, 7, 8

Thallus or colony very large, horizontally spreading, irregular in outline, attaining breadths of 50 cm. or more, and marked by irregularly and often reflexly curving, closely forking and interlacing, rather faintly defined bands or axes, 1 to 2.5 mm. wide, between which a thin sheet, leathery or incrusted, rises, as though inflated, in pustuloid rounded protuberances that in average specimens are 3 mm. to 10 mm. in diameter at the base, and 3 to 7 mm. in altitude, very irregular though rounded-polygonal in plan, and generally all leaning or slightly dragged, often with overlap, in one direction. Intersections of the axes thickened, somewhat depressed and apparently provided with rhizoid anchorages.

The general aspect of the impressions left by the colony described above is shown fairly well in the partly eroded specimen photographed and illustrated in Plate 6. In portions of this specimen the traces of the winding and interlacing, inter-foot axes, marked by slight parallel creases, are indistinctly shown. In some cases convex, smooth-surfaced casts resembling flattened tubes lie close in conformity with the strand grooves or appear roundish in cross-section. They may have filled smooth, hollow, cylindrical interiors of the strands. Even in fragments of the youngest thalli like that seen in Plate 8, figure 1, such tubes, almost surely casts, are seen. The smallest approximate 0.75 mm. in diameter. In the specimens shown in Plate 7, figure 1, and Plate 8, figure 4, several of the protuberances have exactly the aspect of very thin incrustations broken in at the top of the mound.

An example nearly uneroded is shown in Plate 7, figure 2. This displays the drag or deformation of the protuberances, to the right in the view, probably in the direction of the stream current. In this specimen the smooth or almost velvety texture of the surface of the thallus is clearly seen. As in other specimens, some of the pro-

tuberances have the appearance of having been provided with small apical pores, sometimes faintly mammillate. The latter feature is more distinctly seen in Plate 8, figure 4, and Plate 7, figure 1.

The structure of the strands, which may have been tubular, is obscurely indicated in all the photographs, but is more clearly seen in the compressed and deformed specimens illustrated in Plate 7, figures 1 and 3, and in Plate 8, figures 2, 3 and 4.

Inconclusive indications of "holdfast" rhizoids descending from the intersection pits are to be seen in many of the specimens, especially those shown in Plate 7, figure 3, and Plate 8, figure 4.

The general trend of some of the major or master strands is well seen in the figure last named, while in Plate 7, figures 1 and 3, the removal of the tops of some of the protuberances by erosion reveals accumulations of coarse sand with a little magnetite and a few very minute flecks of mica washed into the hollows under the leathery or incrusted cover of the protuberances.

That the inter-strand carpet of the colony was sufficiently tough to resist erosion in a current strong enough to produce wave ripples of the sand where it was not covered by the carpet itself is seen in Plate 8, figure 1. At several points in the figured specimens evidence of rigidity and thickness of the wall is seen in the erosional cross-section. Indications of roundish pits at some of the intersections are rather clearly in view in figure 3 of Plate 7, and in Plate 8, figure 4. We find the strands more clearly defined in a portion of a collapsed and tangled carpet, Plate 8, figure 2, the condition of which may have been due to exposure.

The fossils from the Grand Canyon agree well in essential generic particulars with the specimens from the Keuper of Lorraine, described and photographically illustrated by P. Fliche[1] as *Rivularites repertus.* They differ, however, from the upper Triassic material mainly by the very bluntly rounded protuberances. In the French specimens the protuberances are more pustulose-pointed and are generally much smaller, being not much more than half the diameter of those in the specimens from the Permian of Arizona.

Rivularites was referred by Fliche to the blue-green algæ (*Cyanophyceæ*) on account of the apparently close agreement between the thalli-aggregates from the Keuper and the masses formed by the agglomeration of the living *Rivularia polytes* found on the coast of France. However, the relationship between the fossil and the living *Rivularia* does not seem fully proved. It is interesting to note that in the Triassic material the carpet covering the upward protrusions is likewise described as leathery or incrusted. In view of the definite

[1] Bull. Soc. Sci., Nancy, 3d ser., vol. 6, 1905, page 47, pl. 3, fig. 4.

characteristics recognizable in the fossil and its probable stratigraphic value, generic and specific names must be applied, however questionable may be the systematic status of the fossil.

Rivularites permiensis is not rare in the lower part of the Hermit shale, especially at a point in the Hermit basin about 0.5 mile west of Redtop, where it is found spread on the surface of current ripple-marked slabs of considerable extent. Some of the thalli or colonies are over half a meter in diameter, though most of them are much smaller. All are irregular in lateral configuration and vague in their marginal definition, due, presumably, to lack of development of the tough leathery texture in the new peripheral growth. The plant is almost indubitably algoid, as is indicated by the apparent lack of vascular structure as well as in mode of occurrence, though in some aspects the fossils suggest liverworts.

Evidently the colony carpet was somewhat flexible. In a few cases the aspect of the carpet suggests that it floated or possibly pulsated in the water. The hollows beneath the carpet may have confined gases.

Growth of the plant in a current of water is shown not only by the strong rippling of the fine sandy silts on which the carpet was spread, but by the drag deformation of practically all the protuberances in one direction, which must have been the direction of movement of the current. This is to be noted in nearly every specimen collected. On some of the slabs the silts were washed and lined by the currents beyond and on either side of the colony (Plate 8, figure 1), the tough resistance of which was protective to the sediments beneath. In fact, the surrounding deposits were in some cases considerably worn away by the current without appreciable abrasion of the protuberances of the latter.

Taking into account the relation of the colony to the sedimentary deposit, the texture and adaptation of the carpet to the surface of the deposit, and the physical and palæontological testimony as to occasional evaporation of much of the water in the arroyos, it is suggested that the plant was adapted to survive occasional periods of exposure to the air and drying, as is the case with the algæ in the mud playas of Nevada.

Locality: Rivularites permiensis is relatively abundant in the Hermit Basin, where it is seen only in the hollows (arroyos), the basal portion of the Hermit. A smaller form appears to be present in the middle and lower portions of the Supai formation.

ARTHROPHYTA

SPHENOPHYLLALES

SPHENOPHYLLACEÆ

Sphenophyllum Koenig, 1825

Icones Fossilium Sectiles, pl. xii, f. 149

Sphenophyllum gilmorei D. W. n. sp.

PLATE 9, FIGS. 1-4, PLATE 10, FIGS. 1-6, PLATE 21, FIG. 5

Stems very large, rarely branched, mainly or wholly erect, sometimes as much as 8 mm. in diameter, slightly enlarged upward to the nodes, which are 12 to 80 mm. distant; internodes of general aspect typical of the genus, with, in the impressions, 3 rounded ribs marking the angles of the central stele, and traversed by narrow parallel longitudinal slightly separated strands or faint ribs, apparently 12 in number, spread across the entire width, and probably representing vascular strands external to the central wood; leaf verticils open or somewhat oblique consisting of 6 large, transversely oblong scars, which are flattened somewhat along the upper border, and rounded on the proximal side; leaves very large, more or less round-convex dorsad, thick, broadly spatulate, 15 to 50 mm. long, convexly bordered, widest somewhat above the middle, narrowed above to a broad or obtusely rounded, entire, or faintly erose apex, and very thick at the broad base, where, in some cases, they appear united in a collar in the node; verticils on probably submerged portions, with short leaves oval to elongated oval-rhomboidal, broad at the base, and narrowed toward the top to the narrow rounded apex; lamina thick, coriaceous, generally obscuring the nervation; nerves very close, apparently fasciculate from the thickened base and forking 2 or 3 times at an extremely narrow angle in passing nearly erect, parallel, equidistant, and with slight outward curving, to the border.

The species described above is unlike any other known form of the genus except that described by Schmalhausen,[1] from the Permian above the Artinsk in the province of Kazan, in the Ural Mountain region, under the name *Sphenophyllum stoukenbergi.* The relation of *Sphenophyllum gilmorei* to that species is unmistakable, notwithstanding the specific distinction seen in the very much larger leaves of the Arizona plant, their greater elongation, the closer and more fasciculate nervation, the broadly flaring, funnel-shaped verticils and the normal attitude of the latter with reference to the axis of the stem. Apparently the Arizona material is more coriaceous and more xerophyllous than the plant from the Uralian region. The only European species which even approaches *Sphenophyllum gilmorei* is *Sphenophyllum thoni* Mahr, in which large, very broadly cuneate and even upward-narrowed leaves are sometimes present, as is illustrated by Zeiller in figure 7, Plate 12, of his *Fossil Flora of the*

[1] J. Schmalhausen, Mém. Com. Géol. vol. II, No. 4, 1887, page 5, pl. II, figs. 1-12.

Carboniferous and Permian of the Basin of Brive.[1] Characteristically, however, the larger leaves of *S. thoni* are more or less distinctly laciniate. Further, in that species as well as all other species except *Sphenophyllum stoukenbergi,* the distinctly cuneate form of the normal leaf is maintained.

A notable feature of the Arizona plant is the rarity of branching. In fact I have seen but a single specimen, Plate 10, figure 4, in which the relations of stem parts are such as to make it appear probable that one was a branch of another. In general the plant appears to have been simple, notwithstanding the notable thickness of the axis and the large size of the leaf verticils. In nearly all cases the leaves are still attached, a feature consistent with lack of permanence of water in portions, at least, of the arroyos.

Among the specimens collected are two fragments, evidently from the lower or middle parts of stems, in which greatly reduced leaves at nodes about 9 mm. distant bear sporangia in rows of three or more attached distad to the ventral surfaces by short, curved pedicels. The fructification is of the *Bowmanites* type. Casts of collapsed sporangia are seen in Plate 21, figure 5. The leaves at the top of the figured specimen are normal and sterile though small.

Sphenophyllum gilmorei is one of the most common plants found in the thin sandstones occurring in the erosional hollows at the base of the Hermit shale, near Red Top, in the Hermit basin, though it appears to be relatively rare at other points. There it not infrequently is found mingled with the footprints of primitive amphibians and reptiles in the slime muds covering the surfaces, as illustrated in Plate 3. Evidently the slimes were very soft and plastic when some of the stems fell in, so that the latter were more or less entirely enveloped in the soft material. Occasionally little more than creases, left by the subsidence of the plants and leaves in the viscous silty mud, remain on the bedding planes to show the presence of the immersed plant. If, however, the rock is broken in two, the form and outline of the plant are more clearly revealed, though decomposition may have impaired the state of preservation. Some of the impressions or creases marking the embedded stems show only the profiles of the leaves, as seen in Plate 3. In such specimens the immersed plants strongly suggest the spinal columns of some vertebrate animal.

The same layers of rock which show the molds of the stems and leaves are traversed, vertical to the bedding, by stems which evidently were standing upright when buried. Examples are shown in Plate 9, figures 1 and 2, and Plate 10, figures 5 and 6. The abundant occurrence of these upright stems leaves little doubt that the *Sphenophyllum* were growing *in situ* in the shallow water of the pools in

[1] R. Zeiller, *Bassin Houiller et Permien de Brive:* Part 2, Flore Fossile, 1892.

which the silts settled to cover the fallen fragments, as well as to build up the sedimentary deposits around stems still erect. In some cases the standing stalks pass through several inches of rapidly deposited sandy material. In all these, the verticils of more or less obliquely inclined leaves are normal to the axis of the stem, as shown in Plate 9, figure 2. In fact, I have seen few cases where there was any evidence of obliquity of the verticil to the axis, and these may have been due to the accidents of preservation where fallen stems, in spite of their rigidity, were slightly deformed beneath the cover of sediments.

A notable feature of some of the verticils is the greatly reduced length of the leaf, which gives the verticil a star-like form, illustrated in Plate 10, figures 1, 5 and 6. In these verticils, the leaves, though relatively broad, are very much shorter and much more pointed. Invariably they are thick, rarely revealing nervation, and in many cases the two sides of the leaf form an angle or extremely low keel along the medial line, suggesting an *Annularia.* It is probable that these short, thick verticils, found generally low on the stem, are more or less distinctly peculiar to the portions of the stem which some of the time were below water level.

From the fragments in hand we may conclude that *Sphenophyllum gilmorei* was a relatively stout, rigid, and rather showy plant, as much as 3 feet in height, growing in rather dense groups in the sands of the shallow, intermittent pools. The stems, often standing but a few centimeters apart (Plate 10, fig. 6), sometimes reached a diameter of nearly a centimeter. They were segmented at intervals of 15 to 80 mm. by nodes provided with broadly flaring, funnel-shaped, stellate rosettes or verticils of spreading, paddle-shaped leaves, sometimes curving very gently outward and not infrequently rolled inward at the lateral borders. The verticils of the lower and normally submerged portions of the stem appear to have been reduced to short, ovate, or narrowly diamond-shaped, thick leaves, more pointed at the apex, and ventrally concave and dorsally flatly carinate. The leaf verticils near the top are somewhat smaller, more delicate, and closer together than those farther down on the stem, giving the tops a slightly plumose effect. Here and there along the stems densely placed, small verticils concealed the numerous relatively large, oval sporangia.

The densely coriaceous, thick lamina of the rigid leaf which usually conceals the close, parallel, and relatively rarely forking nerves, and the frequency with which these leaves are rolled inward at the lateral margins, suggest not only an adaptation to a semi-arid climate, but the husbanding of moisture by reduction of the transpiration surface during dry seasons, marked by the reduction, if not advanced evaporation, of the water in the pools.

Locality: This striking species is named after C. W. Gilmore, Curator of Vertebrate Palæontology in the U. S. National Museum, who found semi-submerged stems in the shales bearing footprints of vertebrate animals near "Red Top," in the Hermit basin, where it is abundant in one of the "hollows." Rarely found also near the Bright Angel and Yaki trails.

PTERIDOSPERMAPHYTA

CALLIPTERIDALES

CALLIPTERIDEÆ

Callipteris Brongniart, 1849

Dict. Univ. Hist. Nat., vol. XIII (Tableau), page 66 (17)

Callipteris conferta (Sternberg) Brongniart

PLATE 11, FIGS. 1 and 2; PLATE 12, FIGS. 3-5; PLATE 17, FIG. 4 ?

1709 Filix, * * *, Scheuchzer, Herbarium diluvianum, pl. II, f. 3.

1825 *Neuropteris conferta* Sternberg, Fl. Vorw., vol. 1, fasc. 4 (Tentamen), p. xvii; Ad. Brongniart, Hist. Vég., foss., vol. 1, 1831, p. 249; Sternberg, Fl. Vorw., vol. 2, 1833, p. 75, pl. 22, fig. 5; Goeppert, Gattungen foss. Pfl., 1846, pts. 5, 6, p. 137, pls. 8 and 9, figs. 2-5.

1826 *Neuropteris decurrens* Sternberg, Fl. Vorw., vol. I, fasc. 4 (tentamen), p. xvii, vol. II, fasc. 5-6, p. 75, pl. 20, f. 2.

1828 *Pecopteris gigantea* Brongniart, Prodrome, p. 66 (57); Brongniart, Hist. Vég. Foss., vol. I, 1834, p. 293, pl. 92; Sauveur, Vég. Foss. Terr. houill. Belg., pl. 43, f. 2, 3; Gutbier, Verst. Rothl. Sach., p. 15, pl. 6, f. 4.

1836 *Hemitelites giganteus* (Brongn.) Goeppert, Syst. fil. foss., p. 331.

1838 *Alethopteris gigantea* (Brongn.) Presl, in Sternberg, Fl. Vorw., vol. II, fasc. 7-8, p. 141.

1849 *Callipteris gigantea* Brongniart, Tableau, p. 69 (19); Zeiller, Expl. Carte Géol. France, vol. IV, 1878, p. 64 pl. 67, f. 6, 7.

1849 *Callipteris conferta* (Sternb.) Brongniart, Tableau, p. 66 (17); Schimper, Traité Pal. Vég., vol. 1, 1869, p. 466, pl. 32, figs. 1-4; Marrat, Proc. Liverpool Geol. Soc., vol. 2, 1872, p. 107, pl. 12, fig. 8, 8A; Ad. Roemer, Leth. Geogn., 1, 1876, pl. 58, fig. 5; Text, 1880, p. 192; Schimper, in Zittel, Handb. Pal. (Paleophyt.), 1879, p. 119, text-fig. 94; Fontaine and I. C. White, 2d Geol. Surv. Penn., Rept. Prog. PP, 1880, p. 54, pl. 11, figs. 1-4; K. Feistmantel, Arch. Naturw. Landesdurch. Böhmen, vol. 4, No. 6, 1881, p. 81, pl. 2, figs. 1, 1a; Renault, Cours. bot. foss., vol. 3, 1883, p. 153, pl. XIV, fig. 5, pl. XV, fig. 1; Bureau, Compt. Rend. Acad. Sci., vol. 100, 1885, p. 1550, figs. 1, 2; Credner, Élem. Géol., 6th ed., 1887, p. 512, text-fig. 287; 9th ed., p. 494, text-fig. 320; Schmalhausen, Mém. Com. Géol., vol. 2, No. 4, 1887, p. 8, pl. 2, fig. 22, pl. 3, figs. 1-4; Renault, Pl., Foss. 1888, p. 307, text-fig. 43; Zeiller, Bassin, houill. Autun et Epinac, pt. 2, Fl. foss., 1890, p. 87, pl. 5, f. 3, pl. 6, f. 1-3; Zeiller, Bassin houill. Brive, pt. 2, Foss. Fl., 1892, p. 34, pl. 8, f. 1-2; Potonié, Abh. k. Preuss. Landesanst., N. F., vol. 9, pt. 2, 1893, p. 29, pl. 1, f. 1, 2; Potonié, op. cit., N. F., vol. 21, 1896, p. 28, text-fig. 19; Potonié, Naturw. Wochenschr., 1897, vol. 12, p. 610, text-fig. 4; Potonié, Lehrb. Pflanzenpal., 1897, p. 56, p. 147, text-figs. 143, 22; Potonié, Metam. Pfl. Pal. Thatsachen, 1898, p. 12, text-fig. 4; Pontonié, Zeitschr. f. Prakt. Geol., 1898, p. 247, text-fig. 90; Potonié, Naturw. Wochenschr., vol. 13, 1898, p. 411, text-fig. 5; Potonié, Bergsmansfreund, 1899, p. 27, text-fig. 23; Hoffmann and Ryba, Leitpfl. Paleoz. Steink., 1899, p. 59, pl. 11, f. 1-3; Potonié, in Engler and Prantl, Nat. Pflanzen., Th. 1, Abth. 4, 1900, p. 486, text-figs. 282 and 298; Zeiller, Élem.

Paléobot., 1900, p. 92, fig. 65; Stefani, Fl. Carb, Perm. Toscana, 1901, p. 41, pl. 8, figs. 3-7; Steinman, Einfurh. Pal., 1903, p. 34, fig. 30 A; Zeiller, Bassin houill. Perm. Blanzy et Creusot, pt. 2, 1906, Fl. Foss., p. 68, pl. 17, fig. 2, pl. 18, figs. 1-4; Gothan, Aus d. Natur, vol. 2, 1906, pt. 1, p. 21, text-fig. 9; Gothan, in Potonié, Beschr. foss. Pfl., Pal. Mes. Form., pt. 5, No. 84, 1907, p. 3, text-fig. 1; No. 85, p. 1, text-figs. 1-9, No. 86, p. 3, text-fig. 2 B; Sterzel, Grossherz. Badens Geol. Landesanst., vol. 5, (Karb. Rothl.), 1907, p. 581, pl. 38, figs. 4, 5; Schuster, Geogn. Jahresb., vol. 20, 1907 (1908), p. 215, pl. 8, figs. 2-8; pl. 9, f. 8; Sellards, Univ. Geol. Surv. Kans., vol. 9, 1908, p. 436, pl. 61, f. 12, 13, pl. 63, f. 9, pl. 64, f. 5; Gothan, Entwick, Pfl., 1909, p. 30, text-fig. 18a; Seward, Foss. Plants, vol. 2, 1910, p. 558, text-fig. 367; Gothan, Handwörterb. Naturw., vol. 7, 1912, p. 417, text-fig. 7; Gothan, Vorgesch. Pfl., 1912, p. 65, text-fig. 37; Gothan, Sitzungsb. Ges. Naturf. Fr., 1915, p. 45, pl. 2, f. 1, 1a-b; Gothan, Glückauf, vol. 51, pt. 2, 1915, p. 705, text-figs. 11-13; Potonié, Lehrb. Pflanzenpal., 2d ed., 1919, p. 96, text-fig. 86; Potonié, Zeitschr. f. Bot., vol. 13, 1921, p. 87, text-fig. 12; Gothan, in Guerich, Leitfoss., pt. 3, 1923, pp. 26, 63, text-fig. 18, pl. 21, f. 1.

1862 *Cyatheites confertus* (Sternberg) Geinitz, Dyas oder Zechst. Rothl., pt. 2, p. 141, pl. 27, figs. 1-8.

1869 *Alethopteris conferta* (Sternberg) Weiss, Foss. Fl., Jüngst. Steink. Rothl. Saar-Rh. Geb., pt. 1, p. 73, pl. 6, f. 1-7 pl. 7, f. 3-6, 8; Weiss, Zeitschr. deutsch. Geol. Gesell., vol. 22, 1870, p. 870, pl. 20, f. 4.

1868 *Alethopteris conferta confluens* Weiss, Foss. Fl. Jüngst. Steink. Rothl. Saar-Rh., Geb., pt. 1, p. 79, pl. 6, f. 1, 2.

1869 *Alethopteris conferta deminuta* Weiss, op. cit., p. 79, pl. 7, f. 3.

1869 *Alethopteris conferta lanceolata* Weiss, op. cit., p. 79, pl. 6, f. 4, 4*a;* pl. 7, f. 6.

1869 *Alethopteris conferta progressa* Weiss, op. cit., p. 80, pl. 6, f. 3.

1869 *Alethopteris conferta vulgaris* Weiss, op. cit., p. 79, pl. 7, f. 4-6, 8.

Fronds bi- or tripinnate, the ultimate pinnæ open, close, parallel, nearly touching or slightly overlapping, alternate to subopposite, oblong-linear, or linear, slightly acute, slightly unsymmetrical, much narrowed downward on the distal side near the base, decurrent proximad, with strong, ventrally sulcate, dorsally rounded rachis which is persistent nearly to the apex and punctate with scales; rachis striated, ventrally canaliculate; ultimate pinnæ succeeded by pinnatifid elongated pinnules of the apex of the frond; pinnules alternate to subopposite, open to a right angle to the rachis in the lower portions of the pinnæ and fronds, more oblique near the apex, greatly reduced on the distal side of the base, slightly reduced in length on the proximal side and on down on the parent rachis, oval to linear-oblong, often broadest in the middle, curving outward more or less distinctly, blunt or obtusely rounded at the apex, ventrally convex on either side of the depressed midrib, more or less distinctly united, especially in the upper parts of the divisions, by the decurrent lamina, very close to rather distant; lamina thick, deeply depressed on the midrib, often narrowly reflexed or canaliculate at the border; midrib distinct, decurrent and strong at the base, tapering upward, continuing to near the summit; nervilles oblique, relatively strong, especially at the base, rather distant, usually forking but sometimes simple, except in the larger pinnules, where they are once or twice forked while arching outward and usually reaching the margin obliquely, some of the proximal basal nerves in the interpinnate decurrent pinnules being apparently derived from the rachis.

The specimen shown in figure 1 of Plate 11 is typical of the species as to form and aspect of the ultimate pinnæ. The lamina

of the pinnules is, however, too thick and too villous to reveal the nervation under the conditions of preservation. Traces of chaffy scales on the rachis conform to the xerophytic characters shown in other plants from the Hermit.

In most of the Arizona specimens, such as that photographed in Plate 12, figure 4, the margins of the lamina are more or less distinctly folded backward, and in some cases the plants were evidently withered somewhat prior to burial. One of these, in which the pinnules are rolled back into quill-like forms, is a part of a frond standing erect with reference to the bedding. The plane of the frond is nearly at right angles to the bedding, though the rachis runs obliquely across the complete thickness of the sandstone layer, which is about 30 cm. in thickness. Portions of two other fronds, probably springing from the same plant, lie in the same attitude, vertical to the bedding, one on the end of the same block and one on the back side parallel to the first.

Owing in part to the conditions of deposition, the nervation is seen fairly well only in the single small specimen caught in a slime layer shown on Plate 12, figure 5. In this specimen, from the upper part of a pinna, the evidently thick texture with the slightly rolled border is plainly indicated in the photograph. Some of the nerves are simple, and all of them are oblique and relatively distant. A marked ventral depression along the middle of the rachis is evident in this specimen as well as in that shown in figure 4. Not only do these pinnæ bear the scars left, apparently, by the chaffy scales, but the thick midribs have the impressions of very short, tapering spines, characteristic of the xerophytic phase of the species.

In the reduced size of the fronds, the very much thickened pinnules, and the rather distinctly scabrous clothing of the relatively thick midribs, the representatives of *Callipteris conferta* from the Hermit shale reflect a degree of aridity of climate, or at least an adaptation to a probably distinctly dry season of the year.

The specimen seen in Plate 12, figure 3, was slime covered before burial by an inwash of sand. Thin slime also adheres to portions of the fragment shown in figure 4 of the same plate.

To this species possibly belongs the specimen shown in Plate 17, figure 4, which has, however, certain characters in common with the originals of Plate 12, figure 1, which appears inseparable from the fertile frond tentatively placed with *Yakia*. It is possibly congeneric if not conspecific with the small fragment, Plate 24, figure 1, described as *Supaia* sp. Perhaps all should be referred to *Callipteris*. The irregular order of the pinnules, many of which are subopposite or opposite, seems to preclude any reference of these specimens to *Pecopteris*.

There being few figures of this very common and characteristic plant of the Cosmopolitan Permian flora in American publications, I have cited many illustrations in the synonymy of the species.

Localities: This species is one of the less common plants found in the lower part of the Hermit shale. Most of the fragments are water-worn and more or less obscure. Occasionally, however, they were coated by a thin covering of hardened slime, so that now they stand in relief on the stream-washed and wave-marked surfaces of the silts. The species was collected from the Hermit, near the Bright Angel and Yaki trails.

Callipteris arizonæ D. W. n. sp.

PLATE 13

Fronds dichotomous, the major divisions (possibly the entire frond) being conspicuously asymmetrical. Rachis very thick, dorsally rounded, densely scabrous, and arching outward from the main axis or (if dichotomous) from the opposing division, obovate or obovate-lanceolate, probably obtuse, broadest in the upper portion, and narrowing downward to the base by reduction in the length of the ultimate pinnæ, which are, however, much shorter on the inner than on the outer side of the division or frond; ultimate pinnæ alternate to opposite, close to distant, those on the outer side being much longer, broader, and less numerous than those on the inner side; outer pinnæ oblong-lanceolate, broadest in the upper portion, obtuse, and tapering downward unsymmetrically to the parent rachis, which is provided with pinnules of decreasing length in passing downward, decurrent-wise, to the preceding ultimate pinna; pinnules of the outer pinna ovate to oblong, open nearly at a right angle, alternate to opposite, distant, slightly broader near the middle, obtuse or obtusely rounded at the faintly upturned apex, and rather broadly decurrent along the scaly, ventrally depressed rachis; pinnæ on the inner side of the asymmetrical frond or division narrow, a little distant, longest in the upper part of the division, becoming linear, obtuse, with broad ovate or ovate-round pinnules or lobes, rather closely placed, decurrently united by a narrow wing, and becoming confluent at the apex of the pinnæ; pinnules on the primary (?) rachis crowded and apparently somewhat heteromorphous; lamina thick, depressed concavely over the midrib, ventrally arched near the border, which is thick and apparently rolled backward slightly; median nerves submerged in the thick lamina, slightly decurrent and probably continuous to near the apex of the pinnule. Ultimate nervation not seen.

A single slab bears all that is known of the above described species. There is some evidence of a major axis passing obliquely through the stratum, and at the left of the frond or division, the greater part of which is shown in the photograph, is a basal portion of another foliate rachis, which possibly belongs to the other half of a bifurcated frond, of which the right half only is seen. However, notwithstanding the conspicuous asymmetry and the difference in the development of the ultimate pinnæ and pinnules on the outer

side of the frond as compared with those on the inner side, and taking into account the arcuate habit of the rachis, which is placed nearly *vis a vis* with the base of rachis indicated by the shadowed groove at the edge of the photograph, I am not certain that we have here one half of a dichotomous frond, though that seems rather probable. In any event, we seem to have a frond diverging obliquely from a primary axis toward which it curves in passing upward and in which the leaf is very much broader and more elaborately developed on its outer side than on the side toward the parent axis. The division here presented is quite unlike the normal bipinnate frond of a non-forking type and seems to require dichotomy in explanation of its form and mode of pinnation. Fracture of the rock has removed the outer pinnæ from the upper portion of the specimen.

The aspect of the outer pinnæ is remarkably suggestive of some of the fronds included in the genus *Laccopteris* from the older Mesozoic. The pinnæ on the left of the division are Alethopteroid in form, and if detached might very appropriately be compared with some of the Alethopteroid forms from the Permian referred to *Callipteridium.* On the other hand, portions both of the large outer pinnæ and of the inner pinnæ are so like pinnæ to be found in some of the later phases of *Callipteris conferta* that I was first inclined to refer it to the same species with admission of the possibility that the frond was dichotomous at or near the base. Dichotomy of the frond in forms referred by different palæobotanists to *Callipteris* is not unknown in the uppermost Lower Permian and in the Zechstein, where the round pinnuled group of Callipterids becomes more heteromorphous and where sympodial dichotomy is seen to be more frequently present, especially near the apex of the frond. As illustrating this variability, including dichotomy in fronds described as *Callipteris affinis,* reference may be made to the specimen from an horizon apparently in the lower part of the Zechstein, at Lodeve, in Alsace, described by Zeiller[1] as *Callipteris* cf. *affinis* and the fronds from the base of the Zechstein and the uppermost lower Permian made by Goeppert[2] the basis of *Callipteris affinis.*

The stout rachis and its scaly protection which appears also to have been extended to the ultimate pinnæ, and the thickened lamina with concealed nervation, together with the degree of heterophylly in the reduced pinnules on the main rachis, are in consonance with the general xerophytic aspects of the flora.

In passing it should be noted that the size of the outer pinnæ near what is apparently the base of the frond or division gives aid

[1] R. Zeiller, Bull. Mus. d'Hist. Nat. de Marseille, vol. I, No. 2, 1898, page 27, pl. III, f. 4.

[2] H. R. Goeppert, Foss. Fl. Perm. Form., 1864, page 105, pl. XII, f. 1.

to the view, already discussed, that the real base of the frond is not seen and that this may, after all, be only a division of a probably bifurcated frond in which, as in *Supaia,* the limb, as represented by ultimate pinnæ, descends decurrently while narrowing to the petiole below the bifurcation. In this connection it may be noted that if the ultimate pinnæ in this specimen were represented by pinnules or elongated lobes, the frond, if dichotomous, would be in essentially complete agreement with the fronds of *Supaia* from the same terrane. This specimen, as I view it, is of unusual interest, not only as illustrating the polymorphy in the later development of *Callipteris,* but also as showing the intimate relationship between *Callipteris* and *Supaia.*

Locality: Hermit shale in the Hermit basin.

Callipteris raymondi Zeiller

PLATE 12, FIG. 2, PLATE 36, FIG. 3

Fronds tri- or quadri-pinnate, but very fragmentarily preserved in the Hermit shale collection; penultimate pinnæ linear, slender, acute, with ventrally sulcate rachis, slightly flexuose toward the apex, and very narrowly bordered by the decurrent lamina and interpinnate pinnules; ultimate pinnæ alternate to subopposite, oblique at angles of about 45° to 60°, parallel, close, sometimes touching or slightly overlapping, oblong to linear, widest a little above the base, acute, decurrent; pinnules alternate, close, oblique, relatively widely decurrent along the rachis, and with nearly equal width along the superior rachis in the upper part of the primary pinna, narrowly obcuneate to broadly deltoid or subflabellate on the superior rachis, generally cut obliquely nearly to the median nerve at a very narrow angle into 2 to 7 more or less outward-recurved, narrow, alternate, linear-oblong lobes, 0.25 to 0.50 mm. wide, and more or less abruptly rounded at the summit, which is sometimes widest; lamina thick, coriaceous, sparsely provided with short, bristle-like hairs; nervation generally obscure, ventrally depressed, the decurrent primary nerve being forked at a narrow angle to furnish a nerville for each lobe, and tapering while passing, flexuose, to the upper lobe of the pinnule.

The fragments of this species, two of which are shown in Plate 12, figure 2, and Plate 36, figure 3, are so nearly in agreement with the plant described by Zeiller[1] from the upper Autunien at Charmay, in the basin of Blanzy and Creusot, that I have little hesitation in referring them to this, one of the most delicate and beautiful species of the genus. The example seen in figure 2 of Plate 12 is from the apex of a compound pinna in which the leaves are abnormally long and lax. The very small fragment shown, twice the natural size, in

[1] R. Zeiller, *Bassin houill. et perm. de Blanzy et Creusot,* II, Fl. Foss. 1896, page 71, pl. XVII, figs. 3–5.

Plate 36, figure 3, approaches near the normal aspect of the average specimen of this plant.

Like other plants from the Hermit shale, the material described above is rather distinctly xerophytic in spite of its minute ultimate divisions. The rachis, which is relatively thick in the lower part of the frond, is sparsely scabrous.

Locality: Base of Hermit shale, to the west of the Bright Angel trail, below El Tovar. Also present near the Hermit trail.

Callipteris ? sp.

PLATE 35, FIGS. 1, 1a, 2

Two specimens collected by my colleague, C. W. Gilmore, in 1927, present faint, thin impressions of a bipinnate frond or segment of a frond, both of which are illustrated in Plate 35. The upper pinnules are plaited to correspond to incipient pinnatifidation which appears on the proximal side of a very strong, depressed, ventral, round-canaliculate rachis. The nervation, faintly indicated in a portion of the specimen, is imperfectly shown in the partially retouched photograph, figure 2. The absence, so far as can be observed, of intermediate pinnules along the rachis between the large pinnatifid pinnules or young pinnæ, and the indicated, rather broad decurrence of the lamina between the latter, which range from alternate to subopposite, may be interpreted as showing close relationship to the pinnæ of *Supaia*—a possibility favored by the slightly arcuate shape of the fragment. On the other hand, it is not clear that this pinna is not bilaterally symmetrical. In its bad state of preservation it seems probable that it is symmetrical, on which account, together with the lobation of the pinnules, I am placing it tentatively in the genus *Callipteris,* though admitting the possibility that it may represent an unrecognized bipinnatifid form of *Supaia.*

In a second specimen, Plate 35, figure 1, smaller pinnules with the same nervation as that seen in the upper part of the other are evidently fertile, as shown by the depressions of the lamina about two-thirds of the way from the midrib to the border, which is slightly sinuate to correspond to the slight plications of the lamina. Notwithstanding the Pecopteroid habit of the fragment shown in figure 2 and enlarged twice the natural size in figure 1*a*, I am provisionally including this specimen also in the genus *Callipteris.* The lowermost lobes on the right in figure 1 are, however, somewhat Odontopteroid in aspect. It is important that additional material be gathered to illustrate the features of the development of the frond and the detailed characters of the fructification.

Locality: Lower part of Hermit shale, Hermit basin.

Supaia D. W. new genus

The genus *Supaia* is here established to include a group of Permian and older Mesozoic species of fernlike plants, present in a wide range of forms in the Hermit shale. The principal characters of the genus are bifurcation of the frond into two equal divisions, each of which is simply pinnate or pinnatifid; the divisions, at a narrow angle to each other in most species, are usually more or less distinctly crescentic, arching outward, and asymmetrical, often conspicuously so, with pinnules on the outer sides much longer than those on the inner sides; they are acute or obtuse, with confluent terminal lobes, and are usually widest above the middle, from which point they narrow downward by reduction of the pinnules on the inner sides to short lobes or vestiges at the point of bifurcation, while those on the outer side clothe the rachis, while reducing in length, to a point below the bifurcation of the frond; the pinnules are alternate to opposite, sometimes distant, sometimes overlapping, oblique or open, and are Alethopteroid to Neuropteroid in general form and in nervation, the slender acute pinnules being Alethopteroid, with midribs reaching nearly to the apices, and connate in the upper part of the pinna, becoming more deeply separated, but always united by at least a narrow decurrent lamina in the lower portions of the pinna. In some species the decurrent lamina, which may be relatively broad, is auriculate, and in most cases it is ventrally buckled in a ruffle-like inflation, which is compressed into different forms in the impressions by the flattening both of the wing and of the more or less obliquely set pinnules. The nervation is predominantly Alethopteroid, with nerves springing from the rachis in the decurrent portions of the lamina, which is usually slightly convex ventrally between the mid-nerve and the border.

Most conspicuous of the above named characteristics, which are seen in nearly all of the group of species described in the following pages, are the single bifurcation in the lower part of the frond, the equality of the two divisions, their simple pinnation, their distinct lateral asymmetry, *vis a vis,* and the narrowing of the limb from the upper part of the frond to a point a little below the dichotomy. In the Arizona species the rachis is short and the distance from the base of the frond to the point of bifurcation is not great. Consequently, the narrowing pinnules appear in most cases to reach nearly to the base of the frond.

No evidence of repeated or sympodial dichotomy and no clear case of pinnate lobation of the pinnules is seen in the collections from Arizona now in hand, though under conditions stimulating greater luxuriance, secondary pinnation might take place. All the plants are

leathery or coriaceous; all present characters regarded as distinctly xerophytic.

The simplicity of pinnation of the two divisions is constant in the Hermit flora. Undulation of the margin is seen in one species, *Supaia anomala* (Plate 22), and radially ventrad arching of the lamina in correspondence with marginal sinuosity is present in another species, *Supaia subgoepperti* (Plate 25). These species present the nearest approach to lobation or pinnatifidation of the pinnule, and suggest a tendency toward bipinnatifid divisions of the frond.

The once-dichotomous, simply pinnate frond might be developed with, finally, equal divisions, from a more complex sympodial type in an environment where frond reduction in the direction of simplicity, if not reversion, was useful as a means of resistance to a semi-arid climate, which in this case was characterized by long hot seasons, and sandy soil, probably alkaline at times. The genus *Supaia* is, I believe, the product of environmental adaptation developed from the later phases of the *conferta* group of Callipterids, which in some species shows nearly equal bifurcation. Good examples of the latter are *Callipteris affinis* Goeppert [1] and the plant from Lodeve, described and illustrated by Zeiller [2] as *Callipteris* cf. *affinis*. The mode of frond development of this species is so unmistakably similar to that in *Supaia* as, under the circumstances, to make reasonably certain the common origin of the forms. The secondary pinnation of the plant from the Permian of Lodeve may be viewed as corresponding to a lobation of the outer pinnules of the simply pinnate *Supaia*. It is intermediate between the latter and the late or sympodial type of *Callipteris*. The frond described on an earlier page as *Callipteris arizonæ* (Plate 13) which was probably bifurcated near the base, also should be compared. Its inclusion in *Callipteris* may be questioned.

The usually inward-curving divisions of *Supaia* with their lateral external dilation by the elongation of the outer pinnules in the upper part of the divisions, and the narrowing of the pinnules downward to a point below the bifurcation of the main rachis, as shown in figure 1 (p. 56), or as seen in *Supaia linearifolia* (Plate 23), results in a somewhat lyre-shaped frond, slightly suggestive of the early Mesozoic *Clathropteris*. On the other hand, in some species of *Supaia*, such as *S. sturdevantii* and *S. compacta*, the predominance of the outer over the inner pinnules is very much less marked. The leathery or coriaceous texture and the general masking of the nervation in the thick

[1] H. R. Goeppert, Foss. Fl. Perm. Form., 1864, page 105, pl. XII, fig. 1.

[2] R. Zeiller, Bull. Mus. d'Hist. Nat. de Marseille, vol. I, No. 2, 1898, page 27, pl. III, fig. 4.

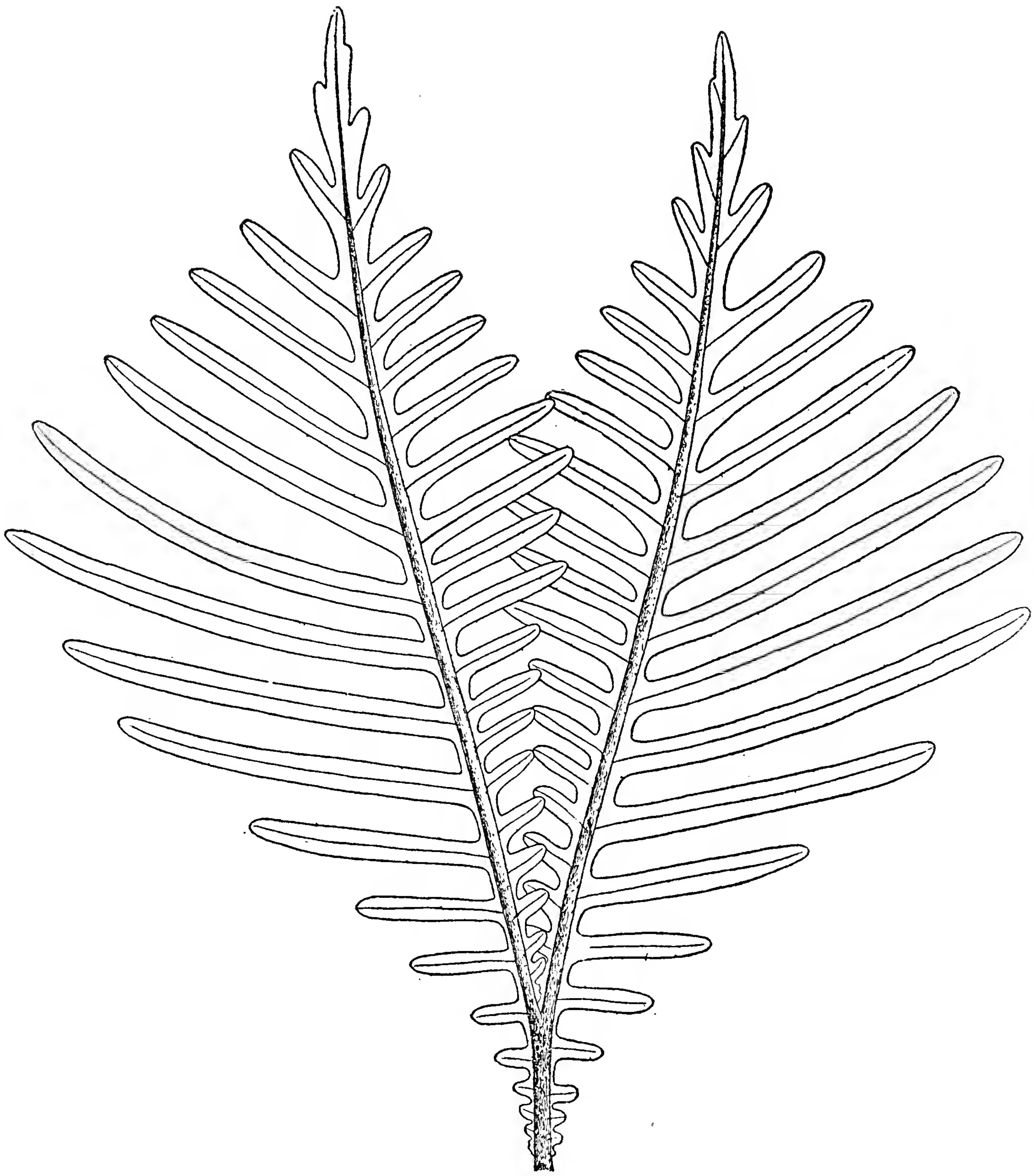


Fig. 1—*Supaia linearifolia.* Diagrammatic restoration of frond. 1/3 natural size.

lamina in the American specimens more probably reflect an unfavorable environment than essential diagnostic characters.

Among other floras the nearest relatives of *Supaia* are found in the Gondwana floras—i. e., the floras characterizing those portions of India, South Africa and South America which, with Australia and possibly Antarctica, embrace the regions of Permian glaciation. They are sometimes collectively and loosely termed the *Glossopteris* floras. As we shall see, some of these relatives are found, also, near the base of the Zechstein in the Uralian region and in floras of very high Lower Permian or possibly Zechstein age in central Asia and central and eastern China where elements from the Gondwana floras mingle with representatives of the Cosmopolitan Permian floras.

The species of *Supaia,* with lanciform pinnules, like *Supaia thinnfeldioides* and *Supaia rigida,* find their most intimate connections in the upper Gondwana flora of the Southern Hemisphere, where, in beds of latest Permian or of Triassic age, in India, Queensland, Victoria, Tasmania, South Africa and Argentina, we meet a group of species with simply pinnate or pinnatifid, equally bifurcated, fronds with elongated or Alethopteroid pinnules which, decreasing in length downward from the middle of the pinnæ, border the rachis for some distance below the bifurcation, and in which the nervation is Alethopteroid with, generally, a well-developed median nerve. Typical in this group of species are those described as (1) *Thinnfeldia lancifolia* (Morris), illustrated by Walkom [1] from the Ipswich and Walloon series of Queensland; by Kurtze [2] from the supposed Rhetic of Argentina and Chile and by du Toit [3] from the upper Beaufort series and lower Molteno beds of South Africa; and as (2) *Thinnfeldia acuta* Walkom [4] from the last named area. These species I believe to be distinctly congeneric with the Hermit *Supaia.* Hardly less strong is the evidence for the assignment to it of some of the species with more typically Neuropteroid characters from South Africa and Argentina.

The impropriety of including the Gondwana species in the same genus with the true European types [5] of *Thinnfeldia,* from the older Mesozoic, was pointed out by Gothan,[6] who established the genus *Dicroïdium* for the bifurcated Gondwana plants previously

[1] A. B., Walkom, *Mesozoic floras of Queensland,* Queensland Geol. Survey Pub. No. 257, pt. 1, page 21, pl. III, fig. 3, pl. IV, fig. 1, 1917.

[2] F. Kurtze, *Atlas d. Plantas Fosiles d. l' Republica Argentina:* Act. Acad. Nac. Cienc. Cordoba, vol. VII, pt. 2, 1921, pl. XVIII, fig. 174, pl. XIX, pl. XX, figs. 267, 270.

[3] A. L. du Toit, *The Fossil Flora of the Upper Karoo beds,* Annals South African Mus., vol. XXII, pt. 2, 1927, page 332, text-fig. 5.

[4] A. B. Walkom, op. cit., p. 23, pl. III, fig. 4; A. L. du Toit, op. cit., page 334, text-fig. 6 A, B, and page 398, text-fig. 23

[5] The European species from the Triassic and Rhetic may with interest be compared with the fragments shown in figures 1, 2 and 3 of Plate 15, or figure 3 of Plate 16.

[6] W. Gothan, *Ueber die Gattung Thinnfeldia Ettingshausen,* Abh. d. Naturh. Gesell. Nürnberg, vol. XIX, No. 3, 1912, pages 67, 75.

included in *Thinnfeldia.* However, the reference which I was at first disposed to make of the Hermit plants to the genus *Dicroïdium,* most of whose species, as differentiated by Gothan, appear to me plainly congeneric with *Supaia,* seems to be precluded by the fact that *Dicroïdium* has as its type species Morris'[1] *Pecopteris odontopteroides,* or *Thinnfeldia odontopteroides* (Morris) Feistmantel, which, though dichotomously forked, is bipinnate. Further, its pinnules, rounded or rhomboidal in form, have an Odontopteroid nervation comparable to that of *Odontopteris osmundæformis,* without well-developed median nerves. The plants with once-forked fronds, the divisions of which are equal and simply pinnate or pinnatifid Alethopteroid, that have been placed in *Dicroïdium,* as well as *Thinnfeldia,* can not, in my judgment, be so classified without violation of the rules of good taxonomic practice. In a purely form classification of fernlike fossil plants, the inclusion of bipinnate fronds, with Odontopteroid pinnules and nervation, in the same genus with simply pinnate Alethopteroid forms, with Alethopteroid pinnules and Alethopteroid nervation, is very plainly objectionable. Therefore, I would refer the Gondwana species with bifurcating simply pinnate or simply pinnatifid fronds and Alethopteroid pinnules to the genus *Supaia,* which is founded on the Hermit plants. The genus *Supaia* constitutes a well-defined and somewhat unique group and its extension to include the Gondwana forms will do much to simplify existing confusion, *Dicroïdium* being restricted, according to present nomenclatural laws, to the bipinnate Odontopteroid types of "*Thinnfeldia.*"

Another bond between the *Supaia* group and the Gondwana flora is found in *Danæopsis hughesi,* of the middle Gondwana of India, and the upper Gondwana flora, apparently, of the entire Southern Hemisphere. An examination of the numerous and excellent drawings of *Danæopsis hughesi* from the South Rewah basin of India, published in Feistmantel's report of the flora of that region,[2] immediately shows a close similarity in essential diagnostic characters between it and the genus *Supaia.* The Gondwana plant, though more robust, due presumably to a more favorable environment, presents the features of frond division, pinnation and nervation seen in *Supaia.* The apex of the pinna is comparable in form to that of *Supaia compacta* (Plate 15, figure 4), while the pinnules are very similar to those of *Supaia merriami* (Plate 19). The pinnules of the southern plant, connate in the upper part of the pinna, are

[1] J. Morris, in Strzelecki's ***Physical description of New South Wales and Van Diemen's Land,*** 1845, p. 249, pl. VI.

[2] O. Feistmantel, Mem. Geol. Survey India, n. s., vol. 4, Pt. 1, p. 24, Plates IV–VII; VIII, figs. 1–5; IX, fig. 4; X; XVII, fig. 1; XVIII, fig. 2; XIX, figs. 1, 2.

decurrent, and in some cases are provided with auricular lobes or small semi-detached lobes at their decurrent bases.

Besides its distribution in the Ipswich series, supposed lower Triassic, of Australia,[1] the upper Beaufort of South Africa,[2] and in the supposed Rhetic of Argentina,[3] *Danæopsis hughesi* is also reported to be present in the mixed flora, along with *Gangamopteris, Nœggerathiopsis, Schizoneura,* and other migrants from the Gondwana province, in the copper sandstones, of lower Zechstein age, in Petchora [4] in northeastern Russia. In China, also, pinnæ very similar to the divisions of *Danæopsis hughesi,* and regarded by Halle[5] as congeneric with the latter, have been described by him from both the Lower and Upper Shihotse series as *Protoblechnum wongii,* the mistake of referring the Gondwana plant with its regularly once-forked frond and *Supaia* type of development of the pinnæ to the Marratiaceous *Danæopsis* of the European Triassic having long been recognized. Later Yabe and Ôishi [6] discovered the last named species in the Chang Chui coal field, Shantung, China, while a very closely related form from the Hei-shan coal field of Shantung was described by them as *Protoblechnum hallei.*[7] From the descriptions, however, it appears that no bifurcation has yet been noted in the Chinese specimens. Therefore, regarding their pinnæ as simple, they are with confidence referred to *Protoblechnum* Lesquereux,[8] which was founded upon *Alethopteris holdeni* of Andrews.[9]

None of the specimens of *Protoblechnum* which I have examined in the collections of the National Museum or at Marietta College, Ohio, show any traces of bifurcation of the frond. On the other hand, the simply pinnate fronds are symmetrical and have broad attachments at the base of the short and downward enlarging petioles. A much closer relationship, which is certainly congeneric if the fronds in the Chinese specimens are simple, is found in the genus *Glenop-*

[1] A. B. Walkom, *Mesozoic Floras of Queensland,* Queensland Geol. Survey, Pub. No. 257, part 1, 1917, p. 24, pl. VII, f. 1.

[2] A. L. du Toit, *The Fossil Flora of the Upper Karoo beds,* Annals South African Mus., vol. XXII, pt. 2, 1927, page 397, pl. XXV; pl. XXVI, fig. 1.

[3] Krasser, Denkschr. K. Akad. Wiss., vol. LXX, 1901, p. 145, pl. II, f. 4. See also, *D. cacheutensis.* F. Kurtze, *Atlas d. Plantas Fosiles d. l'Republica Argentina,* Act. Acad. Nac. Cienc. Cordoba, vol. VII, pt. 2, 1921, page 138, pl. XVI, figs. 198, 199.

[4] M. D. Zalessky, *Flore Gondwanienne du Bassin de la Petchora,* Bull. de la soc. Ouralienne d'Amis. des Sci. Nat. a Ekaterinebourg, vol. XXXIII, 1913, page 14, pl. I, figs. 2-6.

[5] T. G. Halle, *Palæozoic Plants from central Shansi,* Palæontologia Sinica, Geol. Survey of China, ser. A, vol. II, fasc. 1, 1927, page 135, pls. XXXV, XXXVI, and LXIV, fig. 12.

[6] H. Yabe and S. Ôishi: *A Note on Protoblechnum wongii Halle,* Japanese Jour. Geol. and Geog., vol. VI, Nos. 1-2. Sept. 1928, paragraph 61-62, pl. XII.

[7] *A New Species of Protoblechnum from the Hei-shan Coal Field in Shantung,* op. cit., page 15, pl. V.

[8] L. Lesquereux, *Coal Flora,* 2d Geol. Survey of Pa., Rept. P, vol. 1, 1880, page 188.

[9] E. B. Andrews, *Description of the Fossil Plants from the Coal Measures of Ohio,* Rept. Ohio Geol. Survey, 1875, page 428, pl. LI, figs. 1, 2.

teris, described by Sellards[1] from the Wellington shale of Kansas. *Glenopteris,* as will be pointed out in the discussions of the species of *Supaia,* agrees more closely with respect to the forms of the pinnules, the nervation and, in particular, the auriculation of the decurrent lamina, with the Chinese fronds, assuming that the latter are simple, than does the genus *Protoblechnum.* Further, *Protoblechnum* is known only from beds of upper Pottsville age near Rushville, Ohio. No known occurrences of the genus in other parts of the world bridge the gap between the Pottsville and the stage, high in the lower Permian, of the Wellington shale, of which *Glenopteris* is characteristic. Accordingly, I would refer the plants from Shansi and Shantung to the genus *Glenopteris,* as has been suggested by Halle himself, provided they are found to be consistently symmetrical and non-bifurcate. On the other hand, the reference of *Danæopsis hughesi* to *Glenopteris* or *Protoblechnum* is inadmissible on account of its radically different mode of frond development, which is that of *Supaia,* to which I would refer it.

Recognizing the close relations of the *Supaia* group to the middle and upper Permian Callipterids with forking fronds, to which, according to my view, it is most closely bound in origin, comparison should be made of some of the plants of lower Zechstein or upper Rothliegende age described by Zalessky from the Uralian region. Unfortunately the descriptive text to accompany the Atlas on the Permian flora of the Uralian portion of Angara[2] has not been published. However, attention may be called in particular to the photographic illustrations of some of the species described as *Callipteris* and *Odontopteris.* *Callipteris biarmica* Zalessky, Pl. III, fig. 2, of Zalessky's flora of Angaride, has bifurcating pinnæ in which the asymmetrical divisions have the same attitude as in *Supaia* and have Alethopteroid pinnules diminishing in size in descending below the point of bifurcation. The two fragments of *Callipteris demetriana* Zalessky, shown in figure 3 of the same plate are similar in attitude, but breaking of the rock conceals their precise relations. The pinnules of this species are comparable to those of *Supaia sturdevantii* if allowance is made for the relative luxuriance of the Russian flora. Similarly, the fragment of *Odontopteris rossica* Zalessky (op. cit., Pl. IV, fig. 3) invites comparison with *Supaia sturdevantii* and *Supaia merriami.* Two apparently unsymmetrical pinnæ in Zalessky's Plate V, figure 2, *Callipteris uralensis* Zalessky, invite comparison with the basal portion of my *Supaia anomala* shown in figure 4 of Plate 24. The dichotomous character of *Callipteris uralensis,* which apparently

[1] Kans. Univ. Quart., vol. 8, 1900, page 180.

[2] M. D. Zalessky, *Flore Permienne des limites ouraliennes de l'Angaride,* Mem. Comite Geologique, n. s., Livr. 176, 1927.

is sympodial, is shown in Zalessky's Plate VI. Finally, mention should be made of the illustrations of *Odontopteris tatarica* Zalessky (plate XXXVIII), the relations of which, together with those of *Odontopteris rossica* Zalessky (Plate VII), seem to me to fall more closely with *Callipteris* than with *Odontopteris.*

Between *Supaia* and the species tentatively referred by me to Zalessky's *Brongniartites,* of which the descriptions have not yet been published, the affinities are obviously very close. In form of development of the frond there may be no important difference. For the present they may be distinguished by the much greater breadth, the relative basal constriction, and the round apices of the generally shorter pinnules, which are generally concave ventrally; by the less leathery lamina, not so puckered at the proximal angle of the pinnule, and by the coarser, more distant, and more oblique nervation of *"Brongniartites (?)".* The apices of the latter are rounded and somewhat capitate and slightly crenulate.

Largely on the basis of its close relationship to the *conferta* type of *Callipteris,* which is Pteridospermic, the genus *Supaia* also is here classed with the cycadofilices, notwithstanding the description of Marrattiaceous sori on the ventral surface of *Thinnfeldia lancifolia* by Walkom.[1] Strength is added to this classification by the intimate association of seeds with the fronds. Very few seeds, except very small forms probably borne by the gymnosperms, have yet been found in the Hermit. A rather large, slightly cordiform seed has the aspect in detail of being attached to the badly preserved frond shown in Plate 34. Absence of carbonized connecting residues prevents definite correlation of the seed and the rachis to the lower part, below the pinnules, of which it seems joined, so far as can be determined in the impression. The seed which was round-cordate, is probably admissible to the genus *Cyclocarpon,* as is the somewhat smaller seed found in the axil of the pinnule of *Brongniartites (?) yakiensis* shown in Plate 28, figure 1, though the evidence of union is subject to greater doubt in this case. I am inclined to regard the seed at the base of the limb seen in Plate 34 as having grown where it now is.

It is possible, on the other hand, that *Eltovaria* (page 113), a problematic fossil, which I would associate with *Tæniopteris,* was connected with *Supaia.* The polleniferous organs of *"Brongniartites ?"* are, I suspect, borne by slender appendages of the size of fine yarn springing from the axils of the pinnules.

On account of the variation of the pinnules in the parts of the pinna, the differences due to the relative stages of maturity of

[1] A. B. Walkom, *Mesozoic Floras of Queensland,* Queensland Geol. Survey, Pub. No. 257, pt. 1, page 21, pl. III, fig. 3.

the specimens, the nascent stage of development of the genus, and the highly fragmentary character and xerophytic phase of the material collected, the specific differentiation of the Hermit specimens is difficult. It is probable, therefore, that further search will result in the revision of some of the descriptions as well as the reassignments of some of the specimens, especially among those not illustrated. At the same time it now seems probable that the number of species of *Supaia,* which appears to have been specially adapted to the Hermit environment, so as to occupy most of the room for herbaceous plants, will be increased.

The name of the genus is derived from an old Indian name, which was borrowed for application to the Redbeds series of the Canyon wall in which the Hermit shale was formerly included. The type species is *Supaia thinnfeldioides.*

Supaia thinnfeldioides D. W. n. sp.

PLATE 14; PLATE 15, FIGS. 1, 2, 3 AND 5; PLATE 16, FIGS. 2 AND 3

Frond broadly oval, acute at both ends, divisions at a narrow angle, slightly lax, crescentic, short-oblanceolate, broadest above the middle, narrowing downward with convex borders, which on the outer side descend in diminishing width a short distance below the point of bifurcation; rachis thick, tapering, apparently sparsely clothed with chaffy scales; pinnules oblique above, to very wide open below, distant near apex, close or somewhat overlapping in the lower part of the pinnæ, linear-lanceolate, sometimes elongated, tapering gradually upward toward an obtusely pointed apex, curving slightly outward, hardly narrowed at the base except in the lower part of the frond, the reduction being chiefly at the distal sinus, and decurrent or narrowly confluent in the upper part of the frond; lamina thick, almost totally concealing the nervation, nearly flat and arched ventrad a little at the border; midrib rather thick, dorsally in relief, ventrally slightly depressed, tapering but distinct to very near the apex of the pinnule, very slightly decurrent; nervilles slender, decurrent, passing obliquely and nearly straight to the margin, while appearing to fork once in some cases.

The plant illustrated in Plate 14 and Plate 16, figure 3, represents a graceful and unique type that is less rare than other species of this genus in the Hermit flora. In form, size and mode of arrangement of the pinnules, the plant is very closely similar to the larger fragments illustrated by Sellards[1] as *Glenopteris splendens* from the Wellington shale of Kansas, though auriculation, due perhaps to puckering of the decurrent lamina, is but slightly indicated in the Arizona specimens. It is here variable and mostly faint. As to that, it may be mentioned that in some of the small fragments of *Glenopteris splendens,* from Kansas, in the collections of the Geological

[1] Bull. Kans. Univ. Quarterly, vol. 9, No. 4, 1901, page 182, pl. 37, fig. 1, pl. 38, fig. 1, pl. 40.

Survey, it is difficult to see the auricular flap or buckled lamina in the form shown in Sellards's illustrations.

The puckering of the decurrent lamina is imperfectly seen in the small Hermit fragment shown in Plate 16, figure 2, in which, as the result of maceration, the trend, though not the true aspect of the nervation is seen. Wrinkling of the leaf substance masks the true nervation. The latter, as faintly indicated in portions of the fragment photographed in Plate 15, figure 5, is very oblique and nearly straight from the midrib to the margin, which it meets at an angle of about 40 degrees. Forking of the nervilles is probably more frequent than is inferred from the neural tracing in the photographic enlargement (×2) of another specimen, figure 3, of the same plate.

A fragment showing the apex of a pinna belonging almost without doubt to this species is seen in figure 1 of Plate 15. In this example the margins of the lamina appear to be slightly rolled backward.

Supaia thinnfeldioides is immediately suggestive of the Mesozoic genus *Thinnfeldia,* as found in Europe and as illustrated by many authors, though the observation of the bifurcation of the frond and the development of the overlapping, inward-facing crescentic divisions precludes detailed comparison with that genus. On the other hand, the points of similarity between *Supaia thinnfeldioides* and the plants with bifurcated fronds, asymmetrical divisions, and lanciform, decurrent pinnules of Alethopteroid fashion and nervation, from the upper Permian and Mesozoic of Australia,[1] South Africa,[2] and southern South America,[3] described under *Thinnfeldia* and *Dicroïdium* are so close, not only as to their habit of growth but also in detailed characters, that I am disposed to place the lanciform species in the genus *Supaia.* The inclusion of the Hermit plant in the genus *Dicroïdium,* to which I at first referred it, is impossible for the reason that *Dicroïdium,* to which Gothan [4] assigned the simply pinnate dichotomous species, was established to contain bipinnate divisions, with rhomboidal or rounded pinnules having Odontopteroid nervation, the bipinnate Odontopteroid species, *Thinnfeldia odontopteroides* (Morris) Feistmantel, being made the type of the genus.

[1] See *Thinnfeldia acuta* Walkom, Queensland Geol. Survey, Pub. No. 257, 1917, page 23, pl. 3, f. 4, and *Th. lancifolia* (Morris), op. cit., page 21, pl. 4, f. 1, from supposed Triassic beds of Queensland.

[2] See *Th. acuta* Walkom, in A. L. du Toit, *The Fossil Flora of the Upper Karoo Beds,* Ann. So. Afr. Mus., vol. 22, pt. 2, 1927, page 399; text-fig. 23, page 334; text-fig. 6 A, B from the uppermost Permian and from the lower Trias.

[3] See *Dicroidium lancifolium* (Morris) in Gothan, Abh. naturh. Gesell. Nürnberg, vol. XIX, No. 3, 1912, pl. XVI, figs. 2-4, from the Rhetic of Argentina; also see *Thinnfeldia lancifolia* (Morris) Szajn. in F. Kurtze, *Atlas d. Plantas Fosiles d. l. Republica Argentina,* Act. Acad. Nac. Cienc. Cordoba, vol. VII, pt. 2, 1921, pl. XVIII, fig. 174, pl. XIX, pl. XX, f. 267, 270.

[4] W. Gothan, *Ueber die Gattung Thinnfeldia Ettingshausen,* Abh. d. Naturh. Gesell. Nürnberg, vol. XIX, No. 3, 1912, pages 67, 75.

The intimate genetic connection of the Arizona species of *Supaia* with the Gondwana forms is a most interesting feature of the Hermit flora. Some of the bifurcating fronds of the lower Zechstein and possibly uppermost Lower Permian of northeastern Russia, the Uralian portion of "Angara" land, and of western Mongolia command recognition also as taking part in this common origin and remarkable distribution. The relative ages of the floras in the different regions and the probable directions of migration by the Alaska route are briefly discussed in preceding parts of this report (page 35). The occurrence of Gondwana types in the Uralian region in very early Upper Permian time is generally regarded as subsequent to the development of the Gondwana plants as peculiar to the climate and other environmental features following Permian glaciation in Gondwana Land, from which the plants are supposed to have crossed over to northern Russia and western Mongolia, where they are mingled with representatives of the Middle Permian and early Zechstein cosmopolitan flora. It remains to be seen whether discoveries of very late Lower Permian, or possibly basal Upper Permian plants in other regions of Western North America will not disclose the presence of other Gondwana types like *Rhipidopsis* or *Gangamopteris* in this Continent.

Supaia thinnfeldioides has many points of leaf development and nervation in common with some of the plants described as *Danæopsis* or *Protoblechnum* from the Altai, Central Shansi and the Shantung regions of China. So far as I am aware, however, these plants have simply pinnate fronds that do *not* fork and are bilaterally symmetrical. If this holds true they are referable without question to Sellards's genus *Glenopteris*.

Supaia thinnfeldioides is distinguished from other species of the genus in the Hermit shale by its slightly distant, graceful, tapering, outward-curving, pointed pinnules, which are relatively flat.

Locality: Lower part of Hermit shale, in the Hermit basin, 7.5 miles west of Grand Canyon station.

Supaia rigida D. W. n. sp.

PLATE 17, FIGS. 1, 2 AND 3

Fronds oblong-lanceolate, somewhat divergent, acute, with broadly and deeply ventrally sulcate rachis; pinnules subopposite to alternate or opposite, open nearly at a right angle or reflexed in the lower portion of the frond, very distant, straight, linear, rigid, tapering from near the base to the acute or acuminate apex, very narrowly decurrent along the rachis; terminal pinnule linear-lanceolate, with one or two oblique lobes; basal pinnules unknown; midribs strong, ventrally sulcate, dorsally terete, persistent to the apex of the pinnule, hardly decurrent; lamina thick, coriaceous, ventrally convex, and more or less distinctly rolled backward at the border; nervilles concealed in the thick lamina.

This imperfectly known species is represented in the collection by a few fragments, three of which are seen in Plate 17, figures 1, 2 and 3. The lamina is more reduced than that of any other leaf of this genus in the collection. In the fragment shown in figure 1, it is plainly rolled inward (ventrad) as if by withering, and its very narrow linear form is clearly indicated in several of the pinnules. Examination of the latter shows that the midrib though rigid is not so thick as might be inferred from a superficial glance at the specimen. The nervation is not seen.

The reference of the apical portion shown in figure 2 of Plate 17 to this species is subject to little doubt, notwithstanding the absence of detailed nervation, on account of the very narrow tapering rigid pinnules. To this species also belongs the detached fragment of a slender pinnule shown in figure 3 of the same plate.

The Mesozoic aspect of this species is strikingly emphasized by a comparison of our figures with the plants from the Keuper of Thuringia described by Compter[1] as *Cycadites rumpfi* Schenk (*Thinnfeldia spinosa*). In this connection comparison may also be made of the *Thinnfeldia* figured by Kurtze[2] from the Rhetic of Argentina.

A fuller understanding of the development and specific characters of *Supaia rigida* must await the discovery of additional or better preserved specimens. Meanwhile the species is readily distinguished by the very distant, narrow, straight, rigid, acutely pointed pinnules, open nearly at a right angle to the rachis.

Locality: Hermit trail, Hermit basin, 7.5 miles west of Grand Canyon station.

Supaia sturdevantii D. W. n. sp.

PLATE 18, FIGS. 1, 2, 2A, 2B

Divisions lanceolate to linear-lanceolate, broadest at some distance below the apex, narrowing gently in the middle and lower portions, with rather strong, ventrally coarsely rugose, irregularly lineate, dorsally terete rachis; pinnules set somewhat oblique to the plane of the axis, subopposite to opposite or alternate, close, usually overlapping more or less, open or but slightly oblique and usually curving outward, or slightly reflexed, oblong, obtusely rounded at the abrupt and slightly upturned apex, widest above the middle, narrowed by a low rounded curve to the base on the distal side, very slightly narrowed, except in the lowest pinnules, on the proximal side which is decurrent in a downward narrowing and ventrally buckled wing that is generally folded by compression so as to simulate an ear or lobe at the base of the pinnule; midrib strong, distinctly decurrent at the very base, persistent to the apex, dorsally rounded; lamina very thick,

[1] G. Compter, Nova Acta C. L. C. G. Nat. Cur., vol. XXXVII, pl. XVI, figs. 5, 7 and 8.
[2] F. Kurtze, *Atlas d. Plantas Fosiles d. l. Republica Argentina,* Act. Acad. Nac. Cienc. Cordoba, vol. VII, pt. 2, 1921, pl. XVIII, fig. 174, pl. XIX, fig. 267, 270.

rigid, leathery, apparently smooth or finely rugose, thickened at the border, shallowly carinate dorsad by sloping ventrad from either side of the midrib; nervilles nearly invisible within the thick substance of the lamina, apparently coarse, and sometimes, at least, forking once near the base and possibly again while passing straight, parallel, at nearly 45° to the border.

Typical fragments of this species are shown in Plate 18, figures 1 and 2. Apical portions of the pinna are not yet found or have not been correlated. No distinct junction of pinnæ in a dichotomous frond is seen; but the presence of a part of a second pinna, obliquely buried in the rock and converging with that shown in figure 2, is interpreted as indicating forking of the rachis as in other species. Such forking would conform to the inequality of the pinnules on the two sides of the pinna.

The nervation shown only in the very small portion of pinnule in the lower part of the photograph of the last mentioned specimen, enlarged twice in figure 2*b,* is rather more distinctly Alethopteroid than that of most species of the genus in the collections.

The ravages of parasites, probably the larvæ of some Permian insect, are seen in the upper pinnules, photographed, twice the natural size, in Plate 17, figure 2*a.* Comparable mining of the mesophyll of the leaves of *Callipteris conferta* from the Permian of Thuringia is described and illustrated by Potonié. He compares it with the work of the larvæ of Diptera, Microlepidoptera and Rhynchophorous beetles in plants of the present day.

Professor F. M. Carpenter, of the Bussey Institution, who has been kind enough to examine the specimens from the Hermit shale, expresses the opinion that the mining of the mesophyll was the work of an ancient representative of the Coleoptera.

The specimen from the Permian at Crock in Thuringia and that from the Hermit shale in Arizona comprise the earliest examples yet discovered of the work of the leaf-mining larvæ. The suggestion that the mining might have been done by nematodes is discouraged by the fact that so far as known no living nematodes are mesophyll miners. It is interesting to note that in both instances the leaves mined belong to related genera. The tunnels in the leaves of *Supaia sturdevantii* are notably larger than in those in *Callipteris conferta.*

In general form *Supaia sturdevantii* strongly suggests a colossal *Callipteris conferta,* with outward curved and slightly obliquely placed pinnules which are faintly upturned at the apex. The specimen shown in Plate 18, figure 1, lies oblique to the bedding—i.e., it was buried edgewise. At that it extends completely across the edge of a rapidly deposited but cross-bedded rock layer over 2 inches in thickness. It is probable that this rapidly buried pinna is less

deformed than others and reveals the originally oblique attitude of the pinnules with reference to one another as well as to the rachis better than in other specimens. The ventrad buckling of the decurrent lamina at the bases of the pinnules is present in all cases, though generally lobe-formed, due to flattening on the bedding planes.

Supaia sturdevantii differs from other species by the form of its stiff, leathery, overlapping pinnules, which curve outward and are slightly upward-pointed at the rounded apices. The pinna narrows more gradually toward the base than in most of the associated species.

The resemblance between the illustrated specimens of this species, particularly figure 1, Plate 18, and some of the specimens from the classic Permian region, Belebei, in the Ural Mountains, described by Zalessky [1] as *Odontopteris rossica,* is so strong as to leave little room for doubt as to the close relation between the species. The distinct midribs, the continuity of the decurrent median strands down the ventral surface of the rachis, and the form of the pinnules, indicating, as I view them, bifurcation of the frond, tend to confirm the writer's conclusion, already noted, that the Russian specimens above cited belong to the Callipterid group rather than to *Odontopteris,* and possibly to the genus *Supaia,* as it might have developed with a more complex frond in a much more moist habitat.

Locality: Lower part of Hermit shale, Bright Angel trail, below El Tovar.

Supaia merriami D. W. n. sp.

Plate 19

Pinna long, probably linear-lanceolate, with thick, ventrally sulcate, dorsally rounded rachis; pinnules very large, open, opposite to alternate, mainly subopposite, overlapping, broad, oblong, lanceolate or lingulate, obtuse, hardly narrowed at the base except in the lower part of the frond, connate by the somewhat buckled decurrent lamina; midribs not very thick, ventrally narrowly round-sulcate, dorsally raised, hardly decurrent; lamina thick, apparently fleshy, ventrally depressed near the midrib, curved gently backward toward the margin; nervilles generally immersed in the thick lamina, originating at a wide angle, very coarse, sometimes forking once in passing nearly straight or arching slightly to the border, which they meet at a very open angle.

The fragment of pinna shown in Plate 19 represents the largest frond of *Supaia* found in the Grand Canyon collection. The insert in the lower right of the plate continues the frond downward in natural scale. The specimen was evidently somewhat abraded and mutilated, notwithstanding a degree of toughness and rigidity of the leaves, possibly as the result of stream rolling before burial in the rippled sand, the texture of which is very curly.

[1] Mémoires du Comité Géologique, n. s., Livr. 176, 1927, page 37, pl. 4, figs. 3 and 4.

The nervation of the plant, dimly seen in two pinnules in the upper part and in one near the base of the fragment, is very coarsely and distantly *Alethopteroid.* The nerves, where faintly visible, present a tubular aspect, as though provided with capacity for water movement in the leaf of the plant.

In size and close position of the pinnules, as well as in the angle of the latter to the midrib, the specimen figured strongly suggests *Glenopteris splendens.*[1] It differs, however, from that species by the bifurcation of the frond, the arcuate form of the pinna and a degree of inequality in the size of the pinnules on the two sides of the rachis.

Except for the auriculately buckled lamina at the base of the pinnules, *Supaia merriami* is evidently comparable to the probably congeneric species, also having forked fronds, described in the older Gondwana flora as *Danæopsis hughesi.*[2] The latter shows some signs of auriculation or its equivalent in the form of lobes or small pinnules beneath the lingulate pinnules. The incorrectness of referring the Gondwana plant, which is present in India, Australia, South Africa and South America, to the genus *Danæopsis* has been already mentioned. Plants identified by Zalessky as *Danæopsis hughesi,* without mention of dichotomy, are found in the basal Zechstein or copper sandstones of Pechora in northeastern Russia and at other points on the west slope of the Urals and in beds of nearly the same age in the region of the Altai and northwestern Mongolia, in all of which regions it occurs in a flora of Gondwana types mixed with forms characteristic of the Cosmopolitan Permian flora. Specimens regarded as identical with *Danæopsis hughesi* have been reported from the Shihotse series in central Shansi and in the province of Shantung. These plants from central and eastern China appear, according to descriptions, to present simple non-dichotomous fronds, on which account they can not, in my judgment, be with propriety placed in the same genus with *Danæopsis hughesi,* which I view as a *Supaia.* On the other hand, Halle and Yabe and Ôisha, place the supposed simple Chinese forms in the genus *Protoblechnum* Lesquereux, which has been found only in the upper Pottsville of Ohio. It is possible that further discoveries will show that the Chinese specimens, which represent large pinnæ, actually belong to bifurcating fronds, though this appears improbable. If the fronds do not bifurcate, the Chinese examples are, on the character of the petiole, the form of the frond, the pinnules, and the nervation, undoubtedly to be classed in the genus *Glenopteris* Sellards.

[1] E. H. Sellards, Kans. Univ., Quart., vol. IX, 1900, Ser. A, p. 182, pl. xxxvii, fig. 1; pl. xxxviii, fig. 1; xl.

[2] O. Feistmantel, Mem. Geol. Survey of India, Paleont. Indica, ser. XII, vol. iv, pl. 1, 1882, plates i-viii. See especially plate viii, fig. 1.

Supaia merriami is strikingly similar in general aspect to some of the fernlike species from the Triassic of Europe described in the genus *Neuropteridium,* and illustrated especially by *Neuropteridium voltzii.* Its aspect is distinctly Mesozoic, and on this account it is one of the contributors to the general Mesozoic facies of the Hermit flora.

Locality: Hermit trail, Hermit basin, 7.5 miles west of Grand Canyon station, Arizona.

Supaia compacta D. W. n. sp.

Plate 15, Fig. 4; Plate 16, Fig. 4; Plate 26, Fig. 3; Plate 32, Fig. 1; Plate 35, Fig. 3

Divisions relatively narrow, oblong to linear, tapering to an acute apex, and narrowing slowly downward from the broadest part, which is some distance above the middle, with ventrally deeply depressed rachis, above which the pinnules, somewhat obliquely placed, stand forward; pinnules close, touching or slightly overlapping in the lower part of the division, alternate to subopposite and opposite, open nearly to a right angle in the lower part of the pinna, and becoming oblique toward the apex, short, ovate-oblong to oblong and linear-oblong, slightly narrowed at the base on the upper side, decurrent at the proximal angle, with borders relatively even and nearly parallel to near the apex, which is but slightly narrowed and nearly round; lamina somewhat rigid, very slightly convex ventrally between the midrib and the border, relatively smooth and buckled so as to protrude ventrad at the decurrent base of the pinnule; median nerve not very wide, ventrally slightly depressed, dorsally terete, smooth, and passing, while tapering, very nearly to the apex, and but very slightly decurrent at the base; nervation very indistinct in the thick lamina of generally Alethopteroid development, oblique, and forking apparently once or more in passing, relatively straight, to the border.

No large fragments of this species are present in the collection, but the specimens in hand agree so consistently in character that there is little room for doubt that they represent a single rather easily recognized species. Oblong fragments of pinnules with parallel margins, relatively flat and comparatively smooth surfaces, with narrow, ventrally depressed midribs and tapering but slightly to the round apices, are not infrequent. The specimen shown in Plate 16, figure 4, well illustrates the aspect of the detached pinnules, which in general curve outward slightly.

A fragment from the upper part of the pinna in which the large pinnules are becoming shorter and more deeply parted in passing down the pinna is shown in Plate 35, figure 4, and both the angle of bifurcation of the frond and the attitude and form of the rapidly reduced pinnules near the angle are illustrated in Plate 32, figure 1. In this specimen the pinnules, which appear slightly shriveled, are less rigid than in the other examples, but their leathery aspect is well

shown in the photograph, which is retouched only to emphasize the median nerves.

Crinkling and overlapping of the buckled lamina is seen in the figure just cited. As the result of flattening some pinnules appear to be provided with basal auricles which underlap the upper border of the pinnule next below. This buckling of the decurrent wing is better illustrated in the fragment shown in Plate 26, figure 3. Here the deposition was such that the leaf is less completely flattened, so that the deformation of the bases of the pinnules and the decurrent wing is rather clearly illustrated, especially in the lower part of the specimen, where the raised border is eroded.

On account of the close agreement in form and texture of the pinnules, the terminal fragment shown in Plate 15, figure 4, is with little doubt included in the types of this species. The fragment obliquely buried in the sand is slightly dragged, so that the pinnules on the right are steeply inclined and overlapping, while those on the left are slightly drawn apart.

Supaia compacta is more Alethopteroid in facies than any other of the species yet found in the Hermit shale, except *S. breviloba.* It is distinguished from the plant tentatively referred to *Brongniartites* and described on a later page as *Brongniartites (?) aliena,* by the characteristic irregularity in the form of the pinnules of the latter, for while in that species some of the lower pinnules on the pinna, like that shown in Plate 26, figure 1, are Alethopteroid, resembling in some respects the pinnules of *Supaia compacta,* they are in nearly all specimens easily distinguished by their relatively greater width, by their broader decurrence at the base, by the thinner lamina, by the much stronger midribs, which taper rapidly in passing upward, and by the more oblique nervation. The small pinnules of *Brongniartites ? aliena,* as illustrated in the photograph of the small specimen of the latter, figure 2 of Plate 36, have upward-curving nervation of the *Callipteris* type in pinnules that bend more or less distinctly outward. Between *Supaia compacta* and the typical *Brongniartites ? aliena,* as the latter is illustrated by the mature frond shown in Plate 26, figure 4, the distinction is evident.

The form of apex seen in Plate 15, figure 4, is very suggestive of that illustrated by Sellards under *Glenopteris simplex.*[1] In fact, the similarity is even closer in some of the specimens in the collections of the Geological Survey from the Wellington formation of Kansas. It is hardly possible, however, that the nervation in the figured specimen from the Grand Canyon can closely approximate the very loose and irregular type of Alethopteroid nervation seen in the Kansas plant. On the other hand, the apex of the plant from the Grand Canyon

[1] Sellards, loc. cit., page 184, pl. 37, fig. 2; pl. 38, figs. 2 and 3; pl. 39; and pl. 40.

is strongly suggestive of the terminal fragments figured by Zalessky [1] as *Odontopteris rossica.* In my judgment the latter species certainly belongs to the *Callipteris* group, to the latest forms of which *Supaia* is most closely related.

Locality: Hermit shale in the Hermit basin, 7.5 miles west of Grand Canyon station.

Supaia anomala D. W. n. sp.

PLATE 20, FIGS. 1-3, PLATE 21, FIGS. 1-4; PLATE 22; PLATE 24, FIG. 4

Fronds relatively large, very broad, with crescentic divisions extremely wide, reaching a breadth of 30 cm. or more, broadest above the middle and tapering somewhat acutely both upward and downward; rachis strong, dorsally in round relief, ventrally shallowly but broadly sulcate, and rather broadly alate above, very narrowly winged below; apex of the pinna slightly sympodially dichotomous in distant, oblique, narrow, short-linear pinnules, the linear or narrowly lingulate terminal being more or less deeply cut in one or two very short lobes at some distance below the rather obtuse apex; pinnules alternate to subopposite, open at angles of 45° to 60° or more, very distant, sometimes remote, especially near the apex, short-linear near the top, rapidly becoming greatly elongated, linear or ribbon-like, and slightly lax in aspect, reaching lengths of 26 cm. or more and widths of 2 cm., widest near the middle, with gently sinuate or slightly scalloped or obscurely sublobate borders, the scallops being rounded and usually asymmetrically directed distad or even oblique-pointed in the middle and upper portions of the pinnule, and becoming more pronounced in the lower part of the proximal side, which narrows slightly through the lower 10 cm. of the very large pinnules; lamina very thick, apparently thickly pubescent-leathery, generally thickened at the borders, with one or two well-developed buckled lobes or pseudo-auricles below the decurrent base of the pinnule, narrowing nearly to the rachis at the base of the proximad pinnule in the middle and lower parts of the fronds, but broader in the upper part of the frond, where on the distal side of the pinnule it gradually narrows with a flatly convex border to or very nearly to the rachis, except in the upper pinnules; midribs strong, dorsally raised and narrow, persistent though tapering very nearly to the apex; nervation nowhere clearly seen; nerves of the decurrent wing originating obliquely and forking probably twice in passing rather obliquely to the border, the nerves from the midribs passing straighter and very obliquely to the margin.

This unique species, suggestive of the older Mesozoic floras, appears to find no closely comparable Permian plant outside of the Hermit flora. Typical fragments are shown in Plate 20, figures 1 and 3, in the latter of which the nervation is faintly indicated. The apical segment, Plate 21, figure 1, was at first considered as a species of *Megalopteris* but, after comparison with figure 1 of Plate 20, I am unable to regard it except as representing, like that shown in figure 2 of Plate 21, the top of the pinna of *Supaia anomala,* in which I place

[1] M. D. Zalessky, Mém. Com. Géol., n. s., No. 176, pl. 7, f. 2, and pl. 10, f. 4, 1927.

also the original of figure 2 of Plate 20, notwithstanding its narrower decurrent wing. As to the assignment of the segment shown in Plate 22, the case is not so clear on account of the wider and less constricted decurrent lamina above the bases of the pinnules which, themselves, are not so reduced gradually on the distal side of the base as in the other specimens cited. In respect to these differences in particular the original of Plate 22 should perhaps be referred to *Supaia linearifolia,* which, as seen in Plate 23, figure 1, has similar features of the decurrent lamina and open pinnules which also are less narrowed downward to the distal side of the base. The inclusion of Plate 22 under this species is based chiefly on the features of the short pinnules on the left which are sinuate-bordered like those illustrated in other representatives of *S. anomala.* It may belong to *S. linearifolia,* which I am disposed, on the data now in hand, to view as a species distinct from the other.

The inequality in length between the short sinuate-margined pinnules on the left and the greatly elongated pinnules on the right of the same rachis in the specimen shown in Plate 22, is less striking, however, than that observed between the corresponding inner and outer pinnules shown in Plate 23, figure 1.

On the basis of the agreement between the large pinnules of the plant and the mode of decurrence of the lamina in the fragment showing the dichotomy of a young frond, Plate 24, figure 4, and the small pinnules seen on the left in Plate 22, I have referred this fragment also to *Supaia anomala.* Closer spacing of the pinnules near the bifurcation of the frond is characteristic of *Supaia.*

In addition to the differences noted above, *Supaia linearifolia* differs from *S. anomala* by the rigidity of its more leathery pinnules and by the more narrow and more lanceolate and basally constricted pinnules of the apical fragments, one of which is shown in Plate 36, figure 4. The basal lobes in Plate 23, figure 1, conform in general features with the terminal lobes of the cited apical fragment.

Locality: Lower part of the Hermit shale in the Hermit basin, and near the Bright Angel trail, below El Tovar.

Supaia linearifolia D. W. n. sp.

PLATE 23, FIG. 1; PLATE 36, FIG. 4; TEXT-FIG. 1

Divisions very broad, narrowing rather abruptly below and very abruptly above, acute at the distantly sublobate apex, bluntly pointed to the rachis in the contracting base; rachis strong, broadly sulcate ventrally, dorsally raised, apparently scabrous, and bordered a little widely by the decurrent lamina; pinnules distant, oblique except at the base of the divisions, alternate to subopposite or opposite, elongate-linear or narrowly ribbon-like except near the apex and near the bifurcation of the frond where

they become very short, oblong or lanceolate, and obtuse; longest pinnules not yet fully seen, probably 15 cm. or more in length, and about 1 cm. wide, relatively rigid, probably obtuse, narrowed very gently for some distance above the base of the distal side, hardly contracted on the proximal side, which is distinctly decurrent by nearly the full width of the lamina except near the base of the frond, where the wing narrows downward, and the pinnule is a little more distinctly contracted on the distal side; uppermost pinnules very oblique, short-lanceolate, somewhat connate, the lanceolate terminal being sublobate; lamina thick, not rough, leathery in aspect, slightly wavy in the largest pinnules, possibly due to deformation in burial, pitching, in ventral view, gently inward to the midrib, so as to form an extremely shallow angle along the latter; midrib rather narrow, ventrally narrowly depressed, dorsally in relief, tapering gently to the apex, slightly decurrent, even in the highest pinnule, clearly descending on the surface of the rachis; nervilles not seen.

By the distance separating the pinnules and by the remarkable elongation of the latter on the outer sides of the pinnæ, as well as some similarity of form of apical growth, this plant is so related to *Supaia anomala* as to leave some room for doubt as to whether it should not be referred to the same species. Such a reference is encouraged even by the slightly wavy margin of the pinnules seen in Plate 23, figure 1. Also a slight reduction of the lamina toward the base of the distal side of the pinnule seen in some specimens seems to favor the reference of this specimen to that species, though such basal reduction of pinnule is hardly noticeable in the cited figure, in which, however, the decurrent lamina forms a less narrow and less cuneate wing between the pinnules.

Nevertheless, in view of the differences remaining, and in default of additional specimens needed to show better the development of the plant, I feel constrained to treat the specimens in hand as a distinct species. *Supaia linearifolia* appears to be distinguished from *S. anomala* by the narrowness of its greatly elongated and scarcely sinuate-margined pinnules, the relative flatness of the lamina in the vicinity of the rachis, the much less reduction at the distal side of the base in the longest pinnules, and the descent of the lamina essentially without buckling or folding and with less narrowing downward in passing from the base of the pinnule to that preceding. The midrib of the specimens is apparently narrower than in *S. anomala.* Further, not only is the decurrent lamina less raised ventrad along the rachis, but it pitches very slightly toward the mid-nerve, as seen in ventral aspect. As in other species of the genus, the lamina both in the pinnules and in the wing appears to stand slightly above (ventrad) the plane of the rachis.

No nervilles are seen in the fragments referred to this species. However, stray fragments of pinnules, possibly belonging to this type, show obscure traces of very oblique and nearly straight nervilles.

As already mentioned the pinnules of *Supaia linearifolia* seem to have been more rigid than those of *S. anomala,* though narrower and possibly as long or longer. Notable rigidity was essential to maintaining in position, outspread, the greatly elongated slender pinnules in both species. There is no doubt that the fragment of pinna seen in the lower right of figure 1 of Plate 23 represents the mate of the more fully preserved fragment, as is indicated by its attitude, the agreement in the size of the rachis, and the exact accord between the pinnules of the two opposing divisions of the frond as, diminishing, they approach the bifurcation.

A restoration of the frond of this species is shown in reduced scale in text-figure 1 (p. 56).

The extremely rapid, even abrupt, reduction in length of the pinnules in passing down to the point of bifurcation of the frond, indicated in figure 1, Plate 23, is comparable with that seen in *S. anomala.*

The lenticular or oval body shown as extending beneath the long pinnule in the upper left of figure 1, Plate 23, is the cast of a fruit probably specifically identical with others described on a later page as *Eltovaria,* which is regarded, partly on circumstantial evidence, as belonging possibly to the genus *Supaia,* but more probably to *Tæniopteris.*

Locality: Lower part of Hermit shale, near Bright Angel trail, below El Tovar.

Supaia breviloba D. W. n. sp.

PLATE 33, FIGS. 1 AND 1*a*

Pinnæ relatively narrow, linear-lanceolate to linear, acute, compact, with connate pinnules at the apex; pinnules close, touching or slightly overlapping in the middle and upper portions of the pinna, open nearly at a right angle except near the apex, slightly oblique to the plane of the frond, oval or slightly ovate, rounded at the apex, slightly outward-curved, relatively deeply constricted with very narrow sinus on the distal side of the base, decurring by the entire width of the lamina on the proximal side in the middle of the pinna, with more reduced decurrent wing in the lower portion of the pinna; lamina moderately thick, inclined distinctly from the lateral margin inward to the median nerve on the ventral side; midrib not very strong in the upper part of the pinna, more distinct below, persistent very nearly to the apex of the pinnule, dorsally in relief and distinctly decurrent at the base; nervation Alethopteroid; nervilles originating at an oblique angle and forking once or twice while turning outward near the base and passing nearly straight and oblique to the margin, which they meet at an angle of about 45° in the middle of the pinnule.

The specimen figured, Plate 33, figure 1, is the only fragment of this species now in hand in which the pinnules are not rolled inward from the lateral borders with upward curving of the apical portion

so that they are rather broadly synclinal or boat-shaped, as seen in the casts, the keel being dorsad. In profile these pinnæ suggest the outline of *Alethopteris serlii.*

The figured specimen shows the slightly oblique positions of the non-rolled pinnules, which at that are probably flattened somewhat in the course of the compression of the matrix under loading. The general aspect of the pinna is suggestive of the shorter pinnules of *Alethopteris grandini* or one of the Permian Callipteridiums, like *C. gigas,* though the pinnules of the *Supaia* are more distinctly decurrent and deeper incised on the distal side of the base, especially in the lower part of the pinna. The Alethopteroid nervation of the plant is indicated in the photographic enlargement, Plate 33, figure 1*a.*

Supaia breviloba is readily distinguished from other species of the genus by its short, closely placed, oval or obovate pinnules, very broadly rounded at the top, deeply incised on the distal side of the base, which in the lowest pinnules is cut nearly to the midrib, and the distinctly Alethopteroid oblique nervation. In form the pinna suggests some of the fragments illustrated and described by authors as *Thinnfeldia,* from the upper Gondwana floras of the Southern Hemisphere, and especially from beds of supposed Rhetic age in Argentina.

Locality: Lower part of Hermit trail, on west side of the Bright Angel trail, below El Tovar.

Supaia subgoepperti D. W. n. sp.

PLATE 25

Fronds forking at an angle of about 40°, with very broad, lineate, ventrally deeply depressed rachis; divisions broadly overlapping, relatively broad, apparently oval-oblanceolate, but not fully represented by specimens; pinnules slightly oblique above, open nearly at a right angle below, generally a little distant, alternate to opposite, and, near the top, subalternate, oblong-lanceolate to narrowly triangular-lanceolate, the largest lingulate, obtuse to acute at the apex, decurrent, connate above, basally constricted and prominently inflated ventrad on both sides of the base in the lower part of the frond, the ventral convexity being slightly elongated longitudinally; midribs hardly decurrent, straight, strong, tapering gradually, but distinct and ventrally rather broadly depressed to very near the apex of the pinnule; lamina thick, coriaceous, often inclined toward the midrib on the ventral side, and waved by regularly distributed, very oblique, straight narrow waves or plaits; nervation very indistinctly seen, evidently parallel to the waves of the lamina, rather close, and apparently somewhat fasciculate (?) to correspond to the waves, with simple or once-forked intermediate nerves.

The representation of this species in the present Grand Canyon collection is confined to a single slab, shown in Plate 25. At the

top of the fragment is an imperfect and rather obscure impression of the lower part of a frond, in which bifurcation, though almost certain, as indicated by the surface and fracture of the rock, is not absolutely demonstrated.

The principal features distinguishing *Supaia subgoepperti* are the elongated and more or less narrowly triangular pinnules which are straight or nearly so, and their plication.

The ventrad inflation of the lamina on either side of the midrib at the base of the obliquely posed pinnules—a feature characteristic of both *Supaia* and *Glenopteris*—is conspicuously seen. The specimen indicates the development of longer pinnules in the lower part of the frond and nearer the bifurcation than is seen in either *Brongniartites ? yakiensis* or *B. ? aliena.*

Sinuosity of the margin and ventral arching or plaiting in the lamina, in correspondence, offer as near an approach to lobation or a bipinnatifid development of the frond as has been found in the Hermit representation of the genus *Supaia.* Similar and even more marked scalloping of the margin of this lamina is seen in *Supaia anomala,* Plates 20 and 21.

Though the details of the nervation are not visible in the coriaceous or slightly encrusted specimens in hand, it would appear that rather coarse nerves traverse the crests of the ridges. Further, from the aspect of the surface of the lamina, it seems possible that these are primary nerves from which lateral nerves originate near the base, with rapid upward curving and parallel trends toward the margin. There is ground for the suspicion, however, that simple or once-forked nerves spring directly from the midrib in the intervals between the apparently more branched or fasciculate nerves of the ridges.

The resemblance of *Supaia subgoepperti* to the plant identified by Morris as *Pecopteris goepperti,* as the latter is shown in figures 1*b,* 1*c* and 1*e,* of Plate F in the *Geology of Russia* [1] is the basis for the name of the Grand Canyon species. The aspect of our species is so much like that shown by Goeppert [2] under *Neuropteris salicifolia* as to suggest that the plant from the Zechstein of the Belebei district (Ural Mountains) belongs to the same genus and to a very closely related species. The examination of the figure given by Goeppert shows it rather surely to be the right-hand division of a dichotomous frond like that from the Yaki trail.

[1] R. I. Murchison, É. de Verneuil, et A. de Keyserling: *Géologie de la Russie d' Europe et des Montagnes de l'Oural,* vol. II, Paléontologie, 1845.
[2] Foss. Fl. Perm. Form., 1864, page 102, pl. 12, f. 5.

Further knowledge of the features of this interesting plant awaits the collection of additional material.

Locality: Found only near the Yaki trail, near the base of the Hermit shale.

Supaia sp.

PLATE 34

The poorly preserved and slightly weathered specimen shown in Plate 34 is not now specifically determinable, but it has value as showing in ensemble some interesting features of the anomalous group including *Supaia* and the closely related forms here provisionally referred to *Brongniartites.* The dichotomy forms a relatively narrower angle than in most forms. The pinnæ are broadly overlapping and are but slightly curved upward. The largest pinnules, where the pinnæ are widest, are near the top of the frond. Unlike *"Brongniartites?"* the pinnules are here ventrally convex, with decurrent median nerves and, though less close, the upper pinnules resemble those of *Supaia merriami,* of which this possibly is a small and badly preserved frond. The terminal, not seen in the last-mentioned species, may have been short, with two not very widely connate short, oblong, or broadly ovate, rounded lobes.

The upper part of the pinna is very similar to the corresponding portion of *Danæopsis hughesi,* which was so well illustrated by Feistmantel from the South Rewah coal field of India and which I regard as a species of *Supaia.* Traces of pinnules diminishing in size in passing downward for a short distance below the bifurcation, after the manner of *Supaia,* are nearly obliterated below the bifurcation of the frond. It is interesting to note, however, that on the left of the rachis, opposite the point of dichotomy, the mold of a large, broadly cordiform seed sits in the place of a lobe. Its characters are somewhat indistinct, but the impressions of vascular strands are seen in a narrow marginal zone—not recognizable as a wing, but as part of a probably thick fibrous covering—and this fibrous zone appears in the impression to have been originally united by a very short, narrow attachment, about 3 mm. wide, with the rachis.

In the absence of carbonaceous residues admitting of physical tracing, and having only a matrix surface scattered with the more or less vague impressions of fragments of macerated debris, it is more than possible not only that a seed might lodge with its base against a rachis in this way, but even that a part of a torn envelope of the seed or a morsel of other debris might leave an impression suggestive of organic union of seed and rachis. Nevertheless, while the evidence is inconclusive, I am inclined to regard the seed as in its place of growth. That this may actually be the case appears the more possible

since *Callipteris conferta,* to which, as already noted, *Supaia* is related, bore seeds described as *Carpolithes,* and agreeing with forms distinguished as *Cyclocarpon.*

On account of maceration and abrasion the seed on the Hermit slab lacks characters essential for generic classification, but it suggests *Cyclocarpon.*

Locality: Lower part of Hermit shale, near Red Top, in the Hermit basin.

Supaia sp. indet.

Plate 32, Fig. 2; and Plate 33, Fig. 3

By way of placing on record a form of *Supaia* that appears to be different from the foregoing species, but which is not sufficiently represented for diagnostic description, and with the object of presenting more clearly some of the xerophytic features of the Hermit plants, there is photographed in Plate 32, figure 2, a small fragment of *Supaia* broken from a short distance above the point of bifurcation. In this species the pinnules are apparently connate, even in the reduced forms on the outer side of the frond a little above the fork of the latter. The median nerves, shown on the two pinnules at the lower left, are nearly invisible in the succeeding upper pinnules which, due to their texture and the form of the pinnæ, are somewhat cycadaceous in their aspect. I have seen no other species in the Hermit collections in which the pinnules near the base were so far united or so far reduced on the outer sides of the pinnæ at some distance above the dichotomy of the frond.

The leathery texture, which in the original specimen reflects a pubescent aspect of the pinnules, is very imperfectly shown in Plate 32, figure 1. In this photograph the scabrous covering of the rachis is fairly well indicated in the impression left by the dorsal side of the rachis. The photograph has not been retouched.

The xerophytic features of both the pinnule and the rachis are shown also in the photograph of another specimen, enlarged twice the natural size, as figure 3 of Plate 33. Here the impressions left by the scales on the rachis are more distinctly visible. The impression of the pinnules is, however, slightly abraded in consequence of exposure to the weather.

Locality: Lower part of Hermit shale near Redtop, Hermit basin.

Supaia ? sp.

Plate 24, Fig. 1

The specimen illustrated in Plate 24, figure 1, represents an obviously thick leaf in which the lamina is apparently cut rather shallowly in lobes which may have curled by rolling inward somewhat

on the ventral side. No nervation is visible. The slight furrows indicated by deep lines running at right angles from the axis generally to the apices of the lobes suggest a midrib. The actual relief of the specimen is somewhat exaggerated by the mode of illumination in the photograph.

On first receiving this specimen I was disposed to regard it as a poorly preserved pinna from a young frond of *Gigantopteris*. It is more probable that it belongs to *Callipteris* or to *Supaia*. The frequency with which the lobes or pinnules are opposite precludes any reference of the fragment to the genus *Pecopteris*.

It is even possible that the specimen has to do with some type of fructification.

Locality: Lower part of the Hermit shale east of the Yaki trail.

Brongniartites Zalessky, 1927

Mém. Com. Géol., N. S., No. 176. p. 27, pl. 9.

Brongniartites ? yakiensis D. W. n. sp.

Plate 24, Figs. 2, 3; Plate 28, Figs. 1, 2, 3; Plate 29, Figs. 1, 1a, 2, 3; Plate 30; Plate 31, Figs. 1 and 2; Plate 23, Fig. 3; Plate 32, Fig. 3

Fronds relatively small, equally once bifurcated at a narrow angle, obovate-cuneate, tapering downward to a very large, lineate, dorsally rounded, short, chaffy rachis; divisions equal, curving very slightly or straight upward, often nearly erect, always overlapping, distinctly unsymmetrical, broadly oblanceolate, the greatest width about two-thirds the way up the pinna, obtuse or rounded at the capitate sublobate summit, with pinnules becoming shorter downward to the bifurcation, those on the inner side being much shorter than those on the outer; rachis very strong, ventrally narrow and depressed slightly with reference to the plane of the frond, dorsally rounded, lineate and rugose by rough, loosely placed chaffy scales in lower part, continuing to the apex of the frond, while diminishing by issue of very broad lateral divisions or midribs; pinnules longest at two-thirds of the way up the pinna and on its outer side, in series shortening while descending to small rudiments a little below the dichotomy of the frond, subopposite to opposite, or alternate at the apex, open, slightly oblique below the sublobate, broad-rounded, and large capitate terminal, often at a right angle to the rachis, or even reflexed in the middle and lower parts of the pinna, generally nearly touching or slightly overlapping when flat, not distant above, closer below, oval to oblong, reaching a maximum observed length of 15 cm., and a width of 3.5 cm., slightly asymmetrically rounded or very broadly pointed at the apex, widest near the middle, obliquely rounded toward the rachis on the distal side of the base, decurrent on the proximate side by nearly the whole width of the lamina which, while passing downward, with a concave border, to the base of the preceding pinnule is generally folded or buckled so that in many impressions the pinnule appears rounded to the midrib on the lower side; upper pinnules becoming broadly confluent, very short, oblong or even squarrose or slightly rhomboidal, rounded at the apex, decurrent in posture, the two uppermost appearing as slightly developed open lobes of the very large, broadly

rounded, often plaited and faintly sublobate terminal, which sometimes appears slightly erose; midrib very broad, sometimes rigid and at a wide angle to the rachis, but usually more or less distinctly decurrent, traceable for some distance down the ventral side of the rachis, and tapering gradually to the apex of the pinnule; lamina rather thick, somewhat rigid, rather leathery, apparently smooth, usually concealing the nerves, but sometimes inflated between the latter in the partially macerated specimen, and often having the appearance of thickening at the border, which is shruken somewhat in many of the specimens examined; usually the lamina on each side of the pinnule is inclined ventrad, forming an obtuse angle at the midrib, and frequently it is faintly and rather closely plaited obliquely; lateral nerves, originating at a narrow angle, simple or forking once and rarely forking again, while rapidly curving to pass, nearly straight and parallel, from near the midrib to the border, which they usually meet at an angle of less than 45°; borders of the leaves appearing sparsely provided with short slender spines.

This unique species, relatively abundant in the quarry beneath the Yaki trail, is a most interesting representative of the anomalous group of fern-like plants centering in *Supaia.* Its close affinities with the latter are fairly evident and are especially apparent in the younger pinnæ which I am referring to its sister species, *Brongniartites ? aliena.*

Commonly the specimens collected represent portions from the middle of the frond, like those seen in Plate 24, figure 2, or figures 1 and 3 in Plate 28. The detached pinnules are easily recognized by their oval or oblong form, rounded at the summit, narrowed downward deeply on the distal side of the base, and more or less widely decurrent below, according to their position higher or lower in the pinna. It will be noticed that in nearly all specimens the pinnule is ventrally concave. The very shallowly boat-shaped pinnules are shown not only in the photographs cited but in Plate 31, figure 1. In Plate 28, figure 3, the pinnules were evidently somewhat flattened under pressure which has wrinkled them and partly effaced the aspect of rigidity so well preserved in Plate 24, figure 2, Plate 28, figure 1, and Plate 31, figure 1. Another characteristic of the genus as well as the species is the great breadth at the base of the median nerve, which tapers to a vanishing point slightly below the apex of the pinnule.

The fragments of very large pinnules seen in figure 3 of Plate 28 are among the largest found. This specimen illustrates the remarkably rapid reduction of the pinnules on the inner side of the divisions as compared with those on the outer sides. It will be noticed that the left border of the fragment shown in figure 3 catches the rachis of the other half of the frond—that is, the mate of the larger fragment. The pinnules of the two divisions are seen to overlap rather broadly while they are diminishing in length as the point of bifurca-

tion is approached. The examination of other specimens indicates that the very small pinnules in the angle of the pinna are little more than rudiments. The same is true of the lowest pinnules on the main axis a short distance below the point of its bifurcation.

In passing upward in the pinna we find the pinnules cut less deeply on the distal side of the base and more broadly confluent, as is shown in Plate 29, figure 2, and Plate 31, figure 2. The specimen figured is plainly somewhat macerated and was covered with slime which became suncracked by exposure before its final burial. Even in this specimen the pinnules, though apparently softened and flattened, are still somewhat convex dorsally in the upper left portion of the fragment.

Apical fragments are illustrated in figure 1 of Plate 29, shown twice the natural size in figure 1*a*, and figure 3 in Plate 24 and figure 2 in Plate 28. These specimens, which are sublobate at the somewhat capitate apex, reveal the less rigid, wavy and slightly crenulate young pinnules which in Plate 29 are slightly rolled backward at the margin, though in Plate 28 the lobes are convex dorsally, the margins being curved in the opposite direction. The nervation in the apical portions, fortunately well preserved beneath the less coriaceous epidermis, is shown, twice natural size, in Plate 29, figure 1*a*. As seen in Plate 32, figure 3, it becomes relatively coarse a little lower in the pinna. Like the median nerves, the nervilles of the pinnules taper while forking once or twice and arching near the midrib before passing very oblique and nearly straight to the margin. The general aspect of the nervation in the typical carinate pinnule is indicated in the unusually well-preserved fragment shown twice the natural size in figure 2, Plate 24.

The specimen in figure 1, Plate 31, is interesting on account of the waving or plaiting of the lamina on the proximate side of one of the pinnules. This feature, seen only in this specimen, though suggestive of lobation or incipient pinnatifidation of the pinnule, is probably merely the result of pressure and is comparable to the wrinkling seen at the base of the two pinnules succeeding it on the pinna, for it is not accompanied by fasciculation of the nervation nor any indication of special development in the nerve system. The creases are simply parallel to the regular nervation. It will be noted that in this specimen the wing of the lamina bordering the rachis also slopes strongly downward on the ventral side from the margin to the rachis.

The boat-shaped configuration of the pinnules, seen in most of these specimens, with outletting of the ventral synclines into the troughs down the rachis produced by the inclined decurrent marginal lamina, seems to have been well adapted to serve as a drainage sys-

tem. Whether or not the ventral concavity of the pinnules was persistent through the life of the plant or developed in age during dry seasons, and whatever the physiological requirements which called this configuration into existence, the slant of the lamina both in the pinnules and in the rachial border was suited to the capture of rain and its diversion toward the point of growth of the frond. It is more or less distinctly characteristic of the genus. Unfortunately the coarseness of the matrix does not lend itself to the investigation of the details of the epidermal impressions.

Another very interesting feature of this species is the presence of long, slender, lax appendages, several centimeters in length, springing apparently from the axillary or distal sides of the bases of the median nerves and variously disposed, like strands of yarn, over the surface of the pinnules or the matrix. They accordingly are seen, always obscurely, to lie along the midribs or across the lamina or beneath the frond as it happens to fall. Predominantly they curve outward to the sinus of the pinnule, but apparently they are free from their points of origin. On account of the delicacy of these appendages they are always indistinct and difficult to follow wherever in contact with the sand of the matrix. Whether these curious appendages are stipular in nature or play roles in the fructification of the plant remains to be determined. In view of the fact that they appear in some specimens to be dilated, as though knotted or globularly enlarged, at several points near their upper ends, I am somewhat inclined to regard them as filaments supporting clusters of pollen sacs. In any event, I suggest this as a working hypothesis. It is baffling to follow the sinuous and sometimes tangled delicate strands, the length of which may be greater than that of the pinnule. They may be merely stipular or possibly even parasitic. Basal portions of these filaments are indicated in the axils of the pinnules of the specimen shown twice the natural size in figure 2, Plate 24, where they appear to become lost on reaching the margins in the sinuses. They are obscurely indicated in connection with the outer pinnules shown in figure 2 of Plate 29 and figure 1 of Plate 31. See especially the winding, worm-like strand just above the base of the midrib of the lower left-hand pinnule. Another one is seen passing upward from the axil of the pinnule next above. It is lost in passing across the lamina of the next higher pinnule. The examination of the enlargement, twice the natural size, of a portion of the upper part of a pinna seen in Plate 30 shows one of these filaments lying on the lamina of the first and second pinnules from the base on the left. Another, imposed on the lamina of the third pinnule on that side, is more distinctly caught by the camera and is seen to pass diagonally across the dorsal surface of the succeeding pinnule. In order to avoid exag-

geration, the filaments are not retouched in this photograph. Another of the appendages is seen lying lengthwise of one of the pinnules on the left of the specimen, shown twice the natural size, in the unretouched photograph, figure 3, Plate 32. Examples lying in different directions are seen also in figure 1, Plate 28. Pending the acquisition of specimens in better preservation, I will not attempt the delineation of the enlargements very faintly shown, which I think may be polleniferous.

On the dorsal surface of the specimen last cited a small cordiform fruit, about 1 cm. in length, is seen lying against the rachis of the left of the two divisions of frond. Whether this seed, which may be classed under the generic term *Cyclocarpon*, is really attached to the frond is, on account of the absence of carbonaceous matter and the slightly slimy surface of the pinna, uncertain and can not, I believe, be demonstrated. In passing, however, I will add that it has the aspect of being attached to one of the filaments rather than to the rachis, in spite of its contact with the latter. In this connection attention may be called to the presence of another larger cordiform fruit, the base of which is so associated in contact and with traces of fascicular connection with the rachis at the point of the bifurcation of the frond as to make it appear probable that the specimen, shown in Plate 34, is actually in its place of growth. However, opinions on this point may differ. I therefore prefer to await the discovery of other material, more conclusive, before reaching a definite conclusion that seeds of the form shown in the photograph are the fruit of this genus and that they are borne on the frond in the position occupied, possibly accidentally, in the example photographed.

In the development of the pinnæ, the pinnules and the nervation, these bifurcate fronds are obviously related to the genus *Supaia*, as I have already pointed out. However, by its more rigid pinnæ, its capitate apices, its concavo-convex, less twisted pinnules, which are more deeply cut at the distal angle, by the generally concavo-convex lamina of the pinnule, by the very thick and tapering midrib, and by the presence of the stipule-like appendages, its distinction from *Supaia* appears to be generic rather than specific. There being, however, no other genus more nearly related to it than *Supaia*, I was at first inclined to include it in the latter genus rather than to propose a new generic name. Meanwhile, the examination of the Atlas of Zalessky's valuable monograph of the Permian flora of the Uralian limits of Angaria,[1] which has come to hand since the first collection was made from the Hermit shale, shows that forms very similar in the

[1] Mém. Com. Géol., n. s. No. 176, 1927. See pl. IX, fig. 1, pl. X, figs. 1, 2, and 3; pl. XI, fig. 1; pl. XII, fig. 2; and pl. XXXIX, fig. 1.

development of the pinnules and nervation have been illustrated by Zalessky from the copper sandstones of the lower Zechstein, under a new generic name, *Brongniartites* Zalessky. Unfortunately the descriptive text to accompany this memoir has not yet appeared and the plates are therefore without supplementary information other than brief explanations. All of the seven figures represent one species, described by Fischer [1] in 1840 as *Neuropteris salicifolia,* and subsequently discussed by Kutorga and Brongniart. Although without information as to whether the specimens, including Kutorga's and Brongniart's types, are from once-bifurcated fronds, I am, because of the similarity in the development of the pinnules and nervation, inclined tentatively to refer the Hermit specimens to the same genus. It is to be noted, however, that the Uralian plants were growing under more favorable conditions as elements in a far more rank vegetation. They are much more robust, with larger and longer pinnules, some at least of which are pinnatifid. Also it is not clear that the very large rachis in the Russian specimens is so distinctly, not to mention broadly, bordered by the decurrent lamina as in our plant.

Pending the publication of the descriptions of the Angara flora by Zalessky, the reference of this species and that next to be described to the genus *Brongniartites* is provisional. Some of the fragments of *Brongniartites ? yakiensis* resemble the fragments described by Morris as *Odontopteris fischeri.*[2]

The Hermit plants are also related to *Gigantopteris,* a lower Permian type which appears to have found its way, presumably via the Alaska route, from southern China through southern Manchuria and Korea to the mid-Continent region of the United States where it is abundant at some localities in the lower Permian of Oklahoma and Texas.

Localities: Hermit shale on the Yaki and Hermit trails.

Brongniartites ? aliena D. W. n. sp.

PLATE 27, FIG. 1, 2, AND 2*a*; PLATE 23, FIG. 2; PLATE 26, FIGS. 1, 2 AND 4

Fronds very small, very broadly obcuneate or broadly deltoid-obvate, with a thick, rugose and probably scabrous rachis; pinnæ at an angle of about 35°, straight or but slightly curved, overlapping, narrowly oblanceolate-cuneate, much broader and more convex on the outer side of the rachis, obtusely rounded at the slightly narrowed, capitate apex, narrowing downward below the base of the upper one-third, pinnate; rachis of divisions thick, apparently fleshy, tapering rapidly upward but persistent into the terminal pinnule, ventrally broadly and shallowly depressed, dorsally in relief; pinnules mostly opposite but varying upward to subopposite

[1] Bull. Soc. Nat. Moscow, 1840, page 492.

[2] In Murchison (R. I.) de Verneuil (E.) and Keyserling, (A.): *Géol. d. la Russie d' Europe,* etc., 1845, pages 4, 7, pl. F, 3, a-c.

and alternate, slightly oblique above, wide open or even slightly reflexed below, oval or slightly ovate at the point of division of the frond, those on the peripheral side being much longer than those interiorly placed, and gradually elongating with some increase of width to a maximum at about two-thirds of the way up the pinna, where they are oblong-oval, broadly rounded at the apex, often slightly squarrose, or rhomboidal, narrowed downward obliquely on the distal side of the base, decurrent, and very slightly constricted on the proximal side in the broadest part of the pinna, becoming more round-constricted lower in the frond, more broadly decurrent and connate toward the apex and in the younger fronds, the terminal being very short, somewhat capitate, very broadly rounded, broadly connate with the subjacent pinnules, faintly sublobate, and sometimes appearing plicated and slightly crenulate, possibly as the result of contraction; lamina thick, possibly coriaceous and somewhat rigid in the large pinnules, depressed over the thick midrib, slightly concave ventrally and flatly carinate dorsally, often reflexed or folded at the proximal sinus of the pinnule so as to make the latter appear rounded to the midrib; primary nerve strong, dorsally carinate, often hardly decurrent at base, ventrally depressed, straight or curving back very gently, especially in the young or upper pinnules, and vanishing below the apex of the pinnule; nervilles rarely clearly visible, rather close, springing obliquely from the rachis and midrib and simple or forking once or twice, while curving outward a little, before passing nearly straight and very oblique to the margin, in the larger pinnules, or curving upward in the apical and young pinnules.

The frond of this species is developed as in its most closely related congener, *Brongniartites ? yakiensis,* but with very much smaller divisions—less than half the size of those of the latter species—which are rather less capitate; the pinnules are much smaller, sometimes a little distant, but generally overlapping in the young fronds and the upper portions of the mature divisions, with more distinctly Alethopteroid pinnules in the younger portions, and with more narrowly decurrent border in the lower portions.

The form of the pinnules varies in different parts of the frond and in fronds of different stages of development. The fragment with largest pinnules, seen in Plate 27, figure 2, is comparable with the corresponding part and stage of *B. ? yakiensis* seen in Plate 28, figure 3. The *Callipteris*-like phase, Plate 26, figure 4, may similarly be compared with Plate 31, figure 2; and the young terminal, Plate 26, figure 2, with Plate 24, figure 3 and Plate 29, figure 1 of *B. (?) yakiensis.*

Attention is called to the very small, rudimentary pinnules at the base of the pinna, Plate 27, figure 2, which in some cases appear like vestiges or mere scales. In the large fragment, the bifurcation clearly indicated by the mold is not to be doubted. In this specimen the pinnules are dorsally convex-carinate, but not so much as in *B. ? yakiensis.* Further, in this example the pinnules seem to have shrunk while lying in the silt, as is indicated by the apparent withdrawal of

the margins from the outer lines of the impression. Possibly the lamina was very fleshy with lacunose mesophyll.

The nervation faintly shown in several of the pinnules of the specimen, figure 2, Plate 27, is seen more distinctly in the enlargement, figure 2*a*, which corresponds with that in *B. ? yakiensis*, as seen in the same scale in Plate 24, figure 2.

The upper part of a young pinna which I refer to *B. ? aliena* is shown in Plate 27, figure 1. The asymmetry of the specimen which does not reach the base of the pinna is obvious. Plate 26, figure 2, presents a more advanced stage of development of the upper part of a pinna in which both the form and nervation of the outward curving pinnules are of the *Callipteris conferta* type. This form is apparently continued downward into the phase with larger and more mature pinnules shown in Plate 23, figure 2, in which the lower pinnules are indistinguishable from the forms figured in Plate 27. The immature fragment, figure 2, Plate 23, also conforms clearly to the type of *B ? aliena.* Less certainty attaches to the reference of Plate 26, figure 1, to this species, though its higher pinnules, ovate and broadly attached, with stout tapering median nerves, seem to bind it satisfactorily to the same species as the fragment seen in figure 4 of the same plate.

The similarity both in growth and nervation between the fragments shown in Plate 26, figure 2, and Plate 27, figure 1, and the fragments, included by Brongniart[1] in his *Odontopteris (Callipteris) fischeri* is striking. In fact the relative positions of the two Uralian specimens suggest a bifurcating frond like those from the Yaki trail. Of the close relationship between *B. ? aliena, B. ? yakiensis,* and *Supaia subgoepperti* with the plant from the Uralian Permian there is little doubt.

Locality: Hermit shale, Yaki trail.

Yakia, new genus

Yakia heterophylla D. W. n. sp.

PLATE 39, FIGS. 1-8; PLATE 40, FIGS. 1 ? AND 2 ?

Leaf large, a little dense by reason of closeness of divisions of three known orders, slightly lax, the divisions tapering from a little way above the base to the apex; stem or axis large, over 1 cm. wide in the largest recognized fragments, very fleshy, and separated by two indistinct longitudinal ribs into a central, rather distantly lineate, ventrally shallowly round-canaliculate central axis about half the width of the stem, in the macerated specimens, and two lateral border zones, and provided with pinnules or leaflets between the ultimate branchlets; ultimate branchlets

[1] In Murchison, (R. I.), de Verneuil (E.) and Keyserling, (A): *Géol. d. la. Russie d' Europe*, etc., 1845, pages 4, 7, pl. F. 3, a-c.

bipinnate, close, overlapping; ultimate segments distichous, alternate to subopposite, from very open to not less than 50° to the axis, close, about 12 mm. to 20 mm. distant, slightly overlapping, linear to linear-lanceolate, narrowed somewhat downward near the base, and tapering upward to a rather slender, slightly obtuse apex, with border of the lamina decurrent near the tip; ultimate axis fleshy, thick, traversed by a narrow, often sinuous nerve strand, which curves downward to join the central axis of the larger division; pinnules, or leaflets, alternate, open nearly at a right angle in the older divisions, more oblique in the younger, 4 to 8 mm. distant oblong-lanceolate to narrowly triangular-lanceolate, generally slightly upturned or clavate-falcate, narrowed at the base where they are twisted or oblique to the stem, apparently very flaccid, the uppermost being oblong, short, upturned, obtusely rounded at the apex, decurrent and slightly connate, the lower ones oblong or clavate or even obcuneate, 1.5 to 2.5 mm. wide, round at the tip and greatly thickened, convex where shrunken, the larger ones being cut into 1 to 4 very distant, very open to oblique, short, parallel-sided very short lobes which may be nearly as wide as the main leaf, and obtusely, sometimes obliquely, rounded at the tip; superior axis provided with heteromorphous leaves, one between each ultimate division; lamina somewhat lax in the youngest pinnules near the growing tip of the division, but coriaceous and leathery in spite of apparent fragility, apparently forming a rather wide border along some of the lax young pinnæ, shrunken and thickened in the lower parts of most of the specimens.

Fructification tentatively referred to this species consists of groups of generally five oblong sacks (?) closely crowded together to form very large, slightly elongated-rounded sori (?) situated about short columellæ in depressions or pits above the base or near but within the apex of the reduced oblong or short-clavate leaf, and apparently in part, at least, enveloped by the elongated basal lobes of reduced and somewhat specialized pinnules; sporangia (?) spreading radiately at maturity and opening by longitudinal fission along the axial angle.

The genus and species described above are rather common in the Hermit shale, particularly near the Bright Angel trail. Frequently the brown residues of the shriveled pinnæ of different orders have, when disheveled, the aspect of roots, which is heightened by the wrinkled remains of skeleton-like leaves. In ordinary conditions of preservation the plant is, however, rather easily recognized by the shriveled aspect of the axis, by the closely spaced, relatively even and parallel ultimate divisions, and by the rather distant, narrow, crooked leaves, which have the appearance of being irregularly lobed, the entire leaf and the semi-irregular lobes being narrow, sometimes shriveled, sometimes swollen, but slightly leathery except at the top of the branches. The fragments present an interesting group of morphological characters, some of which are more suggestive of the gymnosperm than of the Pteridosperm or the fern. Most of the impressions and sandstone casts represent the lower and middle portions of the ultimate divisions, and in superficial aspect rather strongly suggest some of the distantly leaved conifers of the Permian and older Mesozoic.

The general aspect of the fronds, assuming that they are Pteridosperms or ferns, is seen in figures 1, 5 and 6 of Plate 39. Figure 1 shows the demarcation of the central zone of the larger axis, which in a part of the specimen is shallowly grooved, a feature that would appear to indicate that this is a ventral view of the frond. On the other hand, however, the ultimate divisions of the axis are slightly rounded and a little above the level of the leaves or pinnules, suggesting a dorsal view. The latter interpretation finds further support in the visibility of the nerve of the leaf, which in each leaf or lobe seems to be simple, and which in general is slightly in relief in this view. The nerve strand is readily traced downward, decurrently, deep into the flattened fleshy axis of the ultimate division, and may be followed through the outer zone to the median zone of the major axis, along which it, superposed, runs downward for a short distance, before it is lost in the interior of the axis. It is probable that this decurrent nerve passes down on the ventral rather than the dorsal side of this axis, the collapse of which permits the tentative assumption that the axis was provided by a hollow cylinder of probably no great resistance, surrounded by a thick cortical zone, the spongy or lacunose character of which favored ready collapse. This view is consistent with the obviously fleshy and collapsed ultimate axes of the superior divisions into which the strands from subordinate divisions may in most instances be similarly traced.

The large pinnule is typically crooked-clavate, open nearly to a right angle, and broadly joined at its fleshy base to the rachis. In some cases the pinnules are very slightly zigzag to correspond to the lobation. The lobes, which number from one to six or seven, are alternate to opposite, seldom longer than the width of the lamina of the pinnule, and are obtusely rounded. Generally a trace of a lobe may be seen just above the distal angle at the base of the pinnule, and a lobe on the proximate side not far above the base. The lobes also are open nearly to a wide angle, are short, and rounded at the summit. Not infrequently the pinnule is unequally bifurcated in aspect at the apex. Due to the fact that the lobes do not all lie in the plane of the axis, or of the main blade of the pinnule, they are seldom completely visible, which gives the pinnules an extremely ragged or tattered aspect.

The large pinnule shown in figure 3 is twisted, which causes the narrowed appearance at the base, and the lobes are more or less deformed. A more accurate representation of pinnule and lobe is seen in figure 8, though here some of the lobes are either broken away or folded backward. The specimen shown in figure 5 is relatively well preserved. Many of the pinnules have the appearance of bearing lobes from the ventral surface suggesting an extremely narrow,

reduced pattern of a variety of the Boston fern in which proliferously refined lobes are developed above the plane of the leaf. It will be noted that some of the pinnæ are opposite; others are subopposite and still others are alternate. Heterophyllous growths on the distal sides at the base of the divisions in one specimen suggest *Aphlebia.*

In several fragments referred to *Yakia* the pinnules appear to be reduced to short flatly clavate and slightly sublobate forms, pouched with depressions a little above the base, which are marked by circular pits suggesting the scars of attachment of fruiting organs. (See Plate 12, figure 1.) Appressed longitudinally in the concave side of the pinnule are the impressions of linear-lanceolate sporangia or flaccid appendages apparently attached at or about the scar in the pit. On account of the poor preservation of the specimens, they being mere dim impressions in the fine sand, it is impossible to determine satisfactorily whether the appendages which made the impressions are involucral or sporangial.

Since these specimens are probably referable with little doubt to *Yakia heterophylla,* it becomes equally probable that the fructifications shown in Plate 40, figure 1, are also connected with the same genus and species. Here we have a specimen in which the character of the rachis, the spacing, the angle, and the size of the divisions agree with *Yakia.* The pinnæ retain vestiges of pinnules, in the lower part of which, at positions corresponding to the pits mentioned above, we find clusters of five or six elongated, dorsally convex bracts or sacs closely appressed longitudinally, lying nearly at right angles to the rachis. These appear to correspond to the impressions interpreted as sporangia or as appendages, possibly involucral in nature, noted in the specimen last described. In fact, they are, I believe, to be interpreted as groups of sporangia or pollen sacs, though it is possible that they represent a cupule formed by the lobes of a modified leaf. It will be noted that in most cases they lie close together, converging at the apex as if to form an envelope.

The probability that one of these alternatives is valid becomes somewhat evident on examining the detached clusters scattered on the slightly weathered bedding plane photographed in figure 2 of Plate 40, where we see a number of detached fruiting bodies scattered over the surface of the rock. As sandstone casts they stand in relief or are partly eroded. The fruit consists of five arcuate, oblong, sac-like bodies resembling very large sporangia. They are obtusely rounded at the closely convergent apices, and narrowed slightly at the base, where they appear to be joined to a very short stalk.

Notwithstanding the sporangial aspect of these casts, the texture of the envelope was evidently leathery, as is shown by their

resistance to compression. Further, there is slight evidence of a partition or double wall between the divisions. In some of the specimens the sacs, apparently of the same character as the loose casts, are radially spread and are opened lengthwise and collapsed. They show, nevertheless, an interesting degree of rigidity.

It is, finally, to be remarked that the casts, which because they were freed and rolled about on the surface of the sand may be regarded as mature, are rather shorter than the sporangium-like bodies shown in figure 1.

In short, while there seems little reason for doubt that these fructifications belong to *Yakia heterophylla,* some doubt remains as to whether what seem fructifications in figure 1 are not merely envelopes or cupules in which the actual fructifications with shorter sacs shown in figure 2 were grown.

If the bodies are sporangia rather than pollen sacs, they must be exannulate and comparable to some of the eusporangiate ferns of supposed Marrattiaceous affinities, and may, in spite of their very large size, be compared with *Asterotheca* and *Ptychocarpus.* The mode of dehiscence recalls *Scolecopteris,* of the upper Permian flora, and the fructification is not without similarity, in the grouping of the sporangia also, to the microsporophylls of *Baiera.* Obviously certain features of the frond fragments, the mode of arrangement of the fructifications, and the very large size of the latter, which suggests seeds rather than spore or pollen sacs, provoke inquiry as to whether we do not have to do with seeds instead of sporangia and whether the sporangia-like groups seen in figure 1 are not actually cupulate.

On the whole, however, in view of the fern-like development of the fragments seen, I am inclined to regard *Yakia* as a Pteridosperm related probably to *Callipteris.* The polleniferous bodies of the latter, as described by Grand'Eury,[1] very much resemble *Crossotheca,* while the seeds attributed by him on purely circumstantial but fairly convincing evidence to the genus are small, oval or rounded sacs, with apparently thin vascular envelope belonging to the genus *Carpolithes.* In fact they closely resemble in size and general aspect the seed found in the axil of a pinna of *Yakia* shown, twice the natural size, in figure 4 of Plate 49.

Comparison of the fructification here attributed to *Yakia* may be made with the inflorescence illustrated by Schmalhausen[2] from the Ural region as *Ullmannia bronni.* It may also be compared with the problematical bodies described by Sellards[3] as *Cordaianthus ? sexpartitus* from the Permian of Kansas. The detached fruits or sporangia suggest also the quadrivalvate fruit of *Callitris.*

[1] C. Grand'Eury, Comptes Rendus, vol. 143, 1906, page 644.
[2] Mém. Comité Géol., vol. II, No. 4, 1887, pl. VII, f. 8-10.
[3] Geol. Survey Kans., vol. 9, 1908, page 459, pl. LXII, f. 5, 6.

The detached fruits from the Hermit by their form and size appear more closely to resemble the disordered mass of sporangial groups illustrated by Goeppert under the name *Schutzia anomala* Geinitz than any other illustrated material of Permian age. A cluster seen at the upper margin of Goeppert's figure [1] is distinctly similar in superficial features to some of the isolated clusters shown in Plate 40, figure 2.

The Hermit fruit and even the sterile leaf also present points of some similarity to *Zygopteris cornuta* as figured and described by Zeiller from the mines at Larche in the Basin of Brives.[2] The elongated sporangium of the French specimen is, however, smaller, more numerous in the cluster and—more important—provided by a broad longitudinal dorsal annulus.

Our supposed sporangia also suggest the microspores of *Albertia bronni,* figured by Renault.[3] Among the fossil Pteridosperms, a form comparable to that of the leaf of *Yakia,* is seen in Goeppert's *Sphenopteris oxydata,*[4] now classed as a *Callipteris.* In the plant from the German Permian the pinnules are heterophyllous and apparently subject to shrinkage or retraction as appears to have been the case with the Arizona *Yakia.* The sterile fronds are also to be compared with some of the phases of *Callipteris lyratifolia* and with *Callipteris strigosa.* However, while it seems likely that *Yakia* is related somewhat closely to the Sphenopteroid group of the genus *Callipteris,* it appears to be excluded from the latter genus, by the characters of its rachis, the irregular mode of development of the pinnule, and the mode of decurrence of the vascular system.

Locality: Present in the lower part of the Hermit shale both in the Hermit basin and near the Bright Angel trail, below El Tovar.

Neuropteridium Schimper, 1869

Traité Paléont. Vég., vol. 1, p. 447.

Neuropteridium ? sp.

PLATE 16, FIG. 1

A single obscure fragment in the collection represents a type that is apparently quite different from any other yet found in the Hermit shale. Unfortunately the preservation is so unsatisfactory that the discovery of better material may necessitate some revision of the outlining placed on the retouched photograph.

[1] Foss. Fl. Perm. Form., 1864 Pl. XXIII, fig. 4.
[2] Bassin houill. et Perm. de Brives, pt. 2, Fl. Foss., 1892, pl. IX, f. 5.
[3] B. Renault, Cours. Bot. Foss., vol. 4, 1885, pl. VII, f. 15.
[4] Foss. Fl. Perm. Form., 1864, page 91, pl. XI, f. 1 *a*.

The provisional reference, with much doubt, of this plant fragment to *Neuropteridium* is based upon the rather faintly indicated form of the lobes and the apparent relations of the two divisions of the frond. It is, however, probable that further search will reveal specimens which will show the characters of the plant and which may relegate it to an entirely different genus.

Locality: The specimen was found near the base of the Hermit shale on the west side of the Bright Angel trail.

TÆNIOPTERIDEÆ

Tæniopteris Brongniart, 1928

Dict. Sci. Nat., vol. LVII (Prodrome) p. 69 (61)

Tæniopteris cf. eckhardti Kurtze

PLATE 37, FIGS. 1 AND 2; PLATE 38, FIGS. 1, 1*a*, AND 4

1859 *Tæniopteris eckhardti* Kurtze, Comment. de petrifactis q. i. schisto bitum. Mansfieldensi reperiuntur, pp. 34, 38, pl. 3, f. 1; Ettingshausen, Beitr. z. Flora d. Vorwelt, 1851, p. 3, 5, pl. XIII, f. 2, 3; Gothan, Entwick. Pfl., 1909, p. 64, text-fig. 34*a*; Potonié, Lehrb. Pflanzenpal., 2d ed., 1919, p. 102, text-fig. 95; Gothan, in Gürich, Leitfoss., 1923, p. 77, text-fig. 70.

Fronds simple, coriaceous, reaching a width of 6 cm., linear-lanceolate, blunt, tapering downward cuneately to a very thick midrib, which apparently forms a short pedicel at the base; midrib deeply round-sulcate ventrally, half round dorsally, with narrow thickened border zone; lamina thick, generally slightly convex between midrib and backward-curved border; nerves coarse, simple, or forking once near the point of origin, and passing parallel, about 18 to 22 to the cm., and straight or slightly upcurved, from the margin of the midrib to the border of the frond, which they meet at an angle of about 55°.

Along with the many fragments of *Tæniopteris angelica* are several specimens in which the base is rather rapidly narrowed to a thick midrib and in which the nerves are coarse and relatively distant, being 18 to 22 to the cm., and often slightly upward curved, as shown in Plate 37, figures 1 and 2. In some instances the middle portion of the pinna of these specimens, Plate 38, figure 1, is no wider than the wide leaves of *T. angelica,* next to be described, but the nervation is coarser. The forking of the nervilles where it is present is so close to the midrib that it is difficult to see. The apex of the frond is bluntly acute.

On account of the very close agreement between the specimens from the Grand Canyon and Kurtze's figures and descriptions of *T. eckhardti,* I provisionally place the specimens under this name, believing that the close examination of good examples may show some nerves to fork at the base in the European plant.

The *Tæniopteris* described above differs from *T. angelica,* the middle portions of whose fronds resemble it, by its bluntly acute apex and the more rapidly narrowed base, as is seen by comparing figure 1 of Plate 37 with figure 2 of Plate 36. Further, the nervation of the *Tæniopteris* in hand is noticeably more distant in corresponding portions of the pinna, as is illustrated in figure 1*a* and figure 2, Plate 38.

Localities: West side of Bright Angel trail below El Tovar, Grand Canyon; Lot 7881, U. S. National Museum. Near Red Top, Hermit Trail, Hermit Basin, 8 miles west of Grand Canyon; Lot 7880, U. S. National Museum.

Tæniopteris angelica D. W. n. sp.

PLATE 31, FIG. 3; PLATE 36, FIG. 2; PLATE 38, FIG. 2

Fronds simple, sessile (?), elongate-linear, faintly lanceolate, reaching a length of 50 cm. and a width of 4.5 cm., broadest near the top of the lower third of its length, and tapering gradually and regularly down to the rather strong rachis, the upper two-thirds gradually narrowing, with a slightly convex border, to the apex, which is rather abruptly rounded; midrib of moderate strength, faintly lineate, ventrally round-sulcate between narrow, flat, thick borders, dorsally round-terete, tapering gradually to the apex; lamina thick, flat, or sloping gently from the borders inward to the midrib on the ventral surface and slightly convex ventrally near the borders; nerves moderately strong, simple or forking once within the border of the midrib, and passing straight, even and parallel, about 28 to 30 to the cm., to the border, which they meet generally at an angle of 60° to 70°.

This beautiful species is the most common representative of *Tæniopteris* yet found in the Hermit flora. The very slender, graceful aspect of the form is indicated by the median portion of the leaf seen in Plate 31, figure 3. The apparent narrowing at the top in the photograph is partly due to deformation. A basal portion of the frond is seen in Plate 36, figure 2. The latter shows the ventrally depressed median nerve and indicates the width of the rachial border beneath the lamina of the pinna in a large frond. The nervation of *Tæniopteris angelica* is seen, photographed twice the natural size, in Plate 38, figure 2, which lends itself to comparison with a corresponding portion of *Tæniopteris* cf. *eckhardti* figure 1*a,* viewed in the same magnification. A distal portion of a leaf is seen in Plate 22.

From the appearance of one of the fragments I am inclined to conclude that the fronds of this species were sessile, and that they were clasping at the base in an attachment very slightly, if at all, oblique.

Tæniopteris angelica is distinguished by its very long, ribbon-like pinnæ, which taper very gradually downward as well as upward, the borders being nearly parallel for a long distance in the middle portions

of the pinna. Its nervation, though similar to that in the species last described *(Tæniopteris* cf. *eckhardti)* is distinctly closer and finer in corresponding portions of the pinna. The plant is readily distinguished from *Tæniopteris multinervis,* a common species in the Lower Permian, by its more elongated pinna, and by the straighter and simpler oblique nervation.

A form similar in some respects to the Hermit species is found in the Lower Shihotse series of central Shansi, China, and is described by Halle [1] under the name *Tæniopteris* cf. *schenki* Sterzl. In the Chinese species the coarser nerves arch upward in curving outward and the pinnæ, though very large, are not so slender as in the plant from Arizona.

Locality: Lower part of the Hermit shale near the Bright Angel trail, beneath El Tovar.

Tæniopteris coriacea Goeppert

PLATE 36, FIGS. 1 AND 1*a;* PLATE 37, FIG. 3; PLATE 38, FIG. 3

1864 *Tæniopteris coriacea* Goeppert, Foss. Flora d. Permischen Formation, p. 130, pl. viii, f. 4, pl. ix, f. 2; Sellards, Bull. Univ. Kansas, vol. II, No. 1 (Kans. Univ. Quart., vol. x, No. 1), 1901, p. 2, pl. I, f. 6, 8-12, pl. II, pl. III, f. 1, 2, pl. IV, f. 1, 4.

Fronds narrowly linear, faintly lanceolate, narrowed upward from the lower third, first gradually, then more rapidly, to the very narrow obtuse apex, attenuate downward to a broad midrib at the base, which probably is not petiolate; lamina rather thick, sometimes slightly convex ventrally, especially at the margin; midrib strong, tapering gradually to the top of the leaf, round-sulcate and lineate ventrally, with a relatively broad border in the lower part, and dorsally round-keeled; nervilles simple in the middle and upper parts of the frond, sometimes forking within the border of the midrib in the lower part, rather fine, straight, parallel, and meeting the border at an angle of 70° to 75°.

The species from the Grand Canyon appears to agree as well with the specimens figured and described by Goeppert as with those found by Sellards in the Wellington shale of Kansas. The slender apical portion of the pinna is seen in Plate 38, figure 3, and Plate 36, figure 1, which is reproduced twice the natural size in figure 1*a*. The midrib is relatively large and tapers upward very gradually from the base of the frond. The basal portion of a large pinna of this species is photographed in figure 3 of Plate 37.

Besides the descriptions and illustrations given by Goeppert and Sellards, as quoted above, mention may be made, for purposes of comparison, of the forms from the Upper Shihotse series in central

[1] T. G. Halle, *Paleozoic Plants from Central Shansi,* Palæont. Sinica, Ser. A, vol. 2, Fasc. 1, 1927, page 151, plate XL, f. 5-7.

Shansi described by Halle[1] as *Tæniopteris tingii.* The latter species, though small, slender, and comparable in size and form with *Tæniopteris coriacea,* has very open and relatively distant nerves which fork, often a second time, in passing across the lamina.

Localities: Lower part of Hermit shale. Present both near the Bright Angel trail below El Tovar and near the Dripping Springs Trail in the Hermit basin.

GYMNOSPERMS

GINKGOPHYTA

PRO-GINKGOALES

Psygmophyllum Schimper, 1872

Traité Pal. vég., vol. 2, p. 192

Psygmophyllum ? sp.

PLATE 44, FIG. 7

The impression shown in the photograph, Plate 44, figure 7, is all that is known of this plant. The leaf itself admits of no descriptive details, for its evidently very thick substance seems to have been covered with a sandy slime now "frozen" to it. A basal cuneate lobe is indistinctly indicated on the probably distal side. The leaf was attached by a thick pedicel nearly 4 mm. wide to a rather large and apparently rigid axis, now collapsed but partly exposed, which diagonals very obliquely entirely across the thickness of the rock, so that the blade of the leaf is buried in a plane apparently 6 mm. above that of the stem at the point of attachment.

The fossil in hand is most suggestive of some of the forms from the lower part of the Zechstein and the upper part of the Lower Permian, ranging from the Ural Mountain region to central Shansi in China, described as *Psygmophyllum.* Comparisons may be made with *Psygmophyllum expansum* Brongniart from the Bélebéï district,[2] and *Psygmophyllum mongolicum* Zalessky, from the Angara stage in Mongolia.[3]

In some respects the outline of the fossil is comparable to *Rhipidopsis,* particularly *Rhipidopsis ginkgoides* from the upper Gondwana series of India. The leaves of the latter are, however, generally narrowed down to slender pedicels, whereas the lobes of the Hermit fossil seem to be divaricately developed. Though the tentative reference of this fossil to the genus *Psygmophyllum,* purely on the basis of its configuration, is subject to question, it is rather prob-

[1] Op. cit., p. 158, pl. XLII, f. 1-8.
[2] M. D. Zalessky, Mém. Com. Géol., n. s. livr. 176, 1927, pl. XIII, fig. 1.
[3] M. D. Zalessky, Mém. Com. Géol., n. s. livr. 174, 1918, page 50, pl. VII, f. 4.

able that the plant belongs to one of the Permian stocks related to Ginkgo.

Locality: Lower part of the Hermit shale in the Hermit basin.

CONIFEROPHYTA

ARAUCARIALES

ARAUCARIACEÆ

Walchia Sternberg, 1826

Vers. Fl. Vorwelt, vol. I, fasc. 4 (Tent.) p. xxii

Walchia piniformis (Schloth.) Sternberg

PLATE 41, FIGS. 1-5; PLATE 42, FIGS. 1-5; PLATE 47, FIG. 2

1820 *Lycopodiolithes piniformis* Schlotheim, Petrefactenkunde, p. 415, pl. 23, f. 1a, 2, pl. 25, f. 1; Schlotheim, Merkwürdige Verstein., 1832, p. 11, pl. 23, f. 1a, 2, pl. 25, f. 1.

1826 *Walchia piniformis* (Schloth.) Sternberg, Vers. Fl. Vorw., vol. 1, fasc. 4, p. xxii; Geinitz and Gutbeir, Verst. Rothl. Sachsens, 1849, p. 23, pl. 10, f. 3-7; Geinitz, Leitpfl. Rothl. Zechst. Sachsens, 1858, p. 17, pl. 2, f. 10-13; Geinitz, Zeitschr. d. deutsch. Geol. Gesell., vol. 13, 1861, p. 693, pl. 17, f. 2; Geinitz, Dyas, Zechst. Rothl., pt. 2, 1862, p. 143, pl. 29, f. 7, pl. 30, f. 1 ?, pl. 31, f. 2-4, 6-10?; Dana, Man. Geol., 1863, p. 373, f. 616c; ed. 1880, p. 370, f. 695; ed. 1895, p. 705, f. 1147; Goeppert, Fl. Perm. Form., 1865, p. 236, pl. 47, 49, 52, f. 1-5; Schimper, Traité Pal. Vég., vol. 2, 1870, p. 236, pl. 73, f. 1, 2 ?; Weiss, Foss. Fl. Jüngst. Steink. Rothl. Saar-Rh. Geb., pt. 2, 1871, p. 179, pl. 17, f. 1, 2; Nicholson, Man. Pal., 1872, p. 495, f. 391; Balfour, Stud. Pal. Bot., 1872, p. 72, f. 55, 56; Roemer, Lethæa Geogn., vol. 1, Atlas., 1876, pl. 58, f. 6a, 6b, text, 1880, p. 250; Credner, Élém. Géol., 3d ed., 1876, p. 467, f. 234; 6th ed., 1887, p. 512, f. 289; 9th ed., 1902, p. 494, f. 322; Heer, Fl. Foss. Helv., vol. 1, 1876, p. 57, pl. 18, f. 8-9, pl. 22, f. 1; Zeiller, Expl. Carte. Géol. France, vol. 4, 1878, pl. 176, f. 3, text, 1879, p. 154; Weiss, Abh. Geol. Specialk. Preuss., vol. 3, No. 1, 1879, p. 32, pl. 3, f. 20; Heer. Urwelt Schweiz, 2d ed., 1879, p. 20, f. 32; Saporta, Monde. Pl. Appar. Homme, 1879, p. 186, f. 15 (1-2); Achepohl, Niederrh. Westf. Steink. Geb., 1881, p. 62, pl. 18, f. 7, 13, pl. 19, f. 1, 2, 7, 8, 12, 17; Weiss, Fl. Steink. Preuss., 1881, p. 19, pl. 20, f. 122; LeConte, Elem. Geol., ed. 1882, p. 415, f. 580; Twelvetrees, Quart. Jour., Geol. Soc. Lond., vol. 38, 1882, p. 498, pl. 21, f. 4-5; Lapparènt, Traité Géol., 1883, p. 756, f. 282; Bergeron, Bull. Soc. Géol. Fr., (3) vol. 12, 1884, p. 533, pl. 27, 28; Schenk, in Zittel, Handbuch (Paleophyt.), 1884, p. 273, f. 187; Renault, Cours. bot. foss., vol. 4, 1885, p. 84, pl. 8, f. 1-3; Sterzel, Pal. Abh., vol. 3, No. 4, 1886, p. 293 (59), pl. 28 (8), f. 4. Miller, N. Amer. Geol. Pal., 1889, p. 148, f. 87; Potonié, Naturw. Wochenschr., vol. 3, 1889, p. 165, f. 6; Potonié, Verh. Bot. Ver. Blandenburg, vol. 31, 1889 (1890), p. 141, f. 6; Zeiller, Bassin houill. Perm. Brives, Fl. Foss., pt. 2, 1892, p. 97, pl. 15, f. 1; Sterzel, Foss. Fl. Rothlieg., 1893, p. 110, pl. 9, f. 11. Potonié, Fl. Rothlieg. Thüringen, 1893, p. 218, pl. 31, f. 4, 6; Renault, Fl. Foss. bassin Autun Épinac, Atlas, 1893, pl. 79, f. 1, text, pt. 2, 1896, p. 354. Sterzel, Mitth. Grossherz, Bad. Geol. Landesanst., vol. 3, pt. 2, 1895, p. 302, pl. 9, f. 5; Sordelli, Fl. foss. Insubries, 1896, p. 29, pl. 7, f. 2; Hoffmann and Ryba, Leitpfl. Pal. Steink., 1899, p. 103, pl. 20, f. 4-8; Potonié, Lehrbuch Pflanzenpal., 1899, p. 293, f. 296; Stefani, Fl. Carb. Perm. Toscana, 1901, p. 111, pl. 14, f. 1; Steinman, Einführ Pal., 1903, p. 53, f. 52, 53. Berthoumieu, Rev. Sci. Bournonnais, vol. 16, 1903, p. 101, pl. 2, p. 28; Fritel, Hist. Nat. France, 24*e bis* (Pl. Foss.), 1903, p. 59, pl. 14, f. 2-4; Flahault, Paléobot., 1904, p. 119, f. 37; Langenhahn, Fauna Fl. Rothl. Friedrichroda, 1905, p. 12, pl. 7,

f. 3, 4, 5, 9, 10, pl. 8, f. 7, 9, 10, pl. 9, f. 16; Zeiller, Bass. houill. Perm. Blanzy et Creusot, pt. 2, Fl. Foss., 1906, p. 204, pl. 50, f. 3, 5; Walther, Geol. Heim. Thüringen, 3d ed., 1906, p. 49, f. 27. Paggio, Elem. Pal. (Pl. Foss.), 1906, p. 115, f. 56. Schuster, Geogn. Jahresb., vol. 20, 1907 (1908), p. 232, pl. 10, f. 12, 13; Sellards, Univ. Kans. Geol. Surv., vol. 9, 1908, p. 460, pl. 66, f. 1, 2; Gothan, Entwick. Pflanzen, 1909, p. 53, f. 33*a*; Schullerus, Verh. Mitt. Siebenburg. Naturw., vol. 59, 1909 (1910), p. 126, f. 25. Hardaker, Quart. Jour. Geol. Soc. London, vol. 68, 1912, p. 656, f. 9; Seward, Foss. Plants, vol. 4, 1919, p. 280, f. 745; Potonié, Lehrbuch. Pflanzenpal., 2d ed., 1921, p. 313, f. 248*a*; Kraüsel, Senkenb. Wiss. Mitth., vol. 5, 1923, p. 85, pl. 3, f. 6, pl. 4, f. 9, 10; Laube, Geol. Aufbau Böhmen, 1923, pl. 2, f. 8; Gothan, in Geurich, Leitfoss, pt. 3, 1923, p. 170, pl. 45, f. 6.

1828 *Lycopodites piniformis* (Schloth.) Brongniart, Prodrome, p. 89 (83).

1894 *Walchia piniformis flaccida* (Goeppert) Bosniaski, Atti Soc. Tosc. Sci. Nat., vol. 9, Proc. Verb., p. 169.

1859 *Walchia piniformis latifolia* Gümbel, Denkschr. K. Bayer. bot. Gesel. Regensburg, vol. 4, p. 104, pl. 8, f. 9.

Generally short twigs and branchlets, rigid, clothed with persistent leaves; twigs open at angles of 45° to 90°, rather close, usually touching or slightly overlapping in the impressions, strong and usually straight or turning slightly upward, not always parallel, tapering slowly to a rather blunt tip, the axis rather large and apparently provided with much lacunose tissue beneath a relatively hard and rigid exterior; leaves spirally arranged, rather close, open at a right angle or as wide as 60°, 5 mm. to 20 mm. in length, according to size and maturity of the twig, with very large, broadly decurrent, high carinate bases, quadrangulate in cross-section, with rounded distal axilla, and trending nearly straight in passing from the base outward for most of their length, or turning slowly upward in the lower two-thirds, then curving more rapidly upward and usually more or less distinctly falciform in the upper third, which tapers to an acute or sometimes rather abrupt apex, the angle on the ventral surface being less prominent in the middle and upper portions, the dorsal angle becoming rather broadly rounded; leaf on the superior branch on the proximal side of the twig much longer than the leaves on the twig itself.

Walchia piniformis is an aggregate of similar forms rather than a single species. This is shown by the differences in the characters of branch and leaf gathered under the name, and by the conspicuous differences in the cones attached to these branches. Further, it is premised by the records of the almost world-wide distribution of the species in the Lower Permian outside of Gondwana Land. Some of the highly diverse fructifications which have been referred by different authors to this species probably belong to distinct genera. In spite of the fact that considerable variation is found in the characters of the twigs and leaves within a single species, it is evident that the material from the Permian of different parts of the world figured by authors as *Walchia piniformis* deserves very painstaking examination and more refined specific definition. In the present case I will confine comparisons to particular figures in the literature, while fully illustrating the Hermit plant, as it is imperfectly represented in the sandy impressions.

The specimens from the Hermit shale which I refer to *Walchia piniformis* appear to fall well within the broad limits of the species as figured and described by various European authors. Some of them stand in closest agreement, however, with the type figured by Zeiller [1] from the Basin of Brives. The similarity between the foliage of the latter specimen and that shown in my figure 1 of Plate 41 is evident, though in the Hermit specimens the twigs are not so plumose nor the leaves relatively so long. The leaves on the parent branch below the base of the ultimate twigs are rather longer in the specimen from Lardin. Some of the branches, as much as a centimeter in diameter, among the American material are still clothed with leaves, as shown in Plate 42, figure 5.

Impressions showing the thick decurrent bases and the angularity of the thick leaves are seen in Plate 41, figure 5, and Plate 42, figures 1, 4 and 5. Views of the leaves clothing stems collapsed in aspect are noted in figure 4 of Plate 41, figure 4 of Plate 42, and figure 2 of Plate 47. Those shown in these figures appear broad to near the apex and somewhat lax. The leaf and its pose in the figure last cited suggest some of the illustrations of *W. filiciformis* (Schlothheim) Sternberg. In the specimen photographed in figure 2, Plate 41, some of the leaves seem to be forked, an aspect due perhaps to accident of preservation.

On account of the agreement in general characters of leaf with the other specimens I assign the slender young twigs, Plate 42, figure 2, to *W. piniformis,* with the assumption, apparently warranted by the delicacy and apparent softness of the attached cones, that the fruit also is immature. Specimens probably representing the same form at maturity are seen in Plate 41, figure 3. These cones are not unlike that shown by Zeiller [2] from the Autunien at Charmoi, as *W. piniformis.* They also appear to be in substantial agreement with the cones from Naumberg, ascribed by Geinitz [3] to the same species. That these cones are proper to this species is reasonably well established. The bracts of the Hermit cones appear, so far as they are discernible, rather clearly to agree with some of the leaves of the foliate stems.

Locality: Though nowhere common, so far as observed, fragments of the species are found in the lower part of the Hermit shale in the Hermit basin, and near both the Yaki and the Bright Angel trails.

[1] R. Zeiller, *Bassin Houiller et Perm. de Brive,* Part 2, *Flore Fossile,* page 97, pl. 15, fig. 1, 1892.

[2] R. Zeiller, *Bassin Houiller et Permien de Blanzy et du Creusot,* Part II, *Flore Fossile,* 1896, page 205, pl. 50, fig. 3. The cone seen in figure 5 of Zeiller's plate seems to approach more closely those I ascribe to *Ullmannia.*

[3] Dyas, Part II, 1862, page 143, pl. XXXI, figs. 3, 4.

Walchia dawsoni D. W. n. sp.

PLATE 44, FIGS. 1, 4 AND 4A; PLATE 42, FIG. 6 ?; PLATE 43 ?

1871 *Walchia (Araucarites) gracilis* Dawson, Rept. Geol. Struct. & Min. Res. Prince Edward Island, p. 43, pl. 2, fig. 23-A.

Branches apparently flat, distichous, with close parallel and slender ultimate twigs, hardly tapering until near the blunt apex; leaves close, decurrent, linear-lanceolate, dorsally carinate, curving outward, and in the upper part curving upward and inward uncinnately or more or less distinctly falcately at the rather narrowly acute apex, 3 to 6 mm. long, and broadest at the base, which is slightly carinate dorsad.

Some confusion exists in the American literature as to the characters of the plants listed under the name *Walchia gracilis* Dawson (non Emmons). The examination of the figure of *Araucarites gracilis* first published by Dawson[1] and republished by him in several other papers, in which the original very brief description, also, is reproduced, and comparison of them with the figure given by him in 1871 in the report on the *Geologic Structure and Mineral Resources of Prince Edward Island* (page 43, pl. 2, fig. 23A), leaves little room for doubt that the plant from Miminigash, in Prince Edward Island, is specifically different from that earlier figured from Nova Scotia. The illustrations vary too much to permit acceptance as representing identical species, notwithstanding that both plants are evenly distichous, with very slender parallel twigs and small leaves.

As shown by comparison of Plate 44, figure 4, with Dawson's illustration of the specimen from Prince Edward Island, the fragments from the Hermit shale appear to differ in no essential character. The slightly greater rigidity and the apparently thicker leaves of the Hermit specimen, figure 4*a,* may reflect merely a more unfavorable climate.

In general form, development and relations of the ultimate branchlets, and in the size, form and attitude of the leaves, the specimen from Prince Edward Island is evidently very closely related to that described by *Brongniart* [2] as *Fucoides hypnoides,* later referred to *Walchia.* In fact it is possible that it should be included in the European species. I hesitate, however, to make this reference on account of the very steadily tapering and blunt appressed leaves of the plant from Lodève, whereas the leaf of the tree from the Permian of Canada, as shown in detail by Dawson, is much more slender, tapering mainly toward the tip, which is, however, slender, acute and

[1] *Araucarites gracilis* Dawson (non Oldham and Morris, nec Walkom), Can. Nat., vol. VIII, 1863, page 433 (33); Dawson, Quart. Jour. Geol. Soc. London, vol. XXII, 1865, page 146, pl. 6, f. 14; Dawson, Acad. Geol., 2d ed., 1868, page 425, text-fig. 159-A; Dawson, Geol. Hist. Pl., 1888, page 135, text-fig. 60 A.

[2] Ad. Brongniart, Hist. Veg. Foss., vol. 1, 1828, page 84, pl. 9-Bis, figs. 1 and 2.

more strongly upturned near the apex. On the whole it seems highly improbable that a comparison of the American material with typical European specimens of *Walchia hypnoides* will result in the consolidation of the form here described as *W. dawsoni* under the European name. Certainly it is widely different from the fragment from the Hermit shale that, on the basis of its approximate agreement with *W. hypnoides* as figured by Zeiller from the upper Autunian, I tentatively refer to the latter species. Meanwhile, the name *Walchia gracilis* is retained, at least pending the examination of material from Nova Scotia, for the material from Tatagouche, in which the ultimate twigs are apparently more rigid and more distant, while the leaves are generally more lax, obliquely placed, and irregular in aspect as well as, apparently, more slender than in *W. dawsoni*. The slime-coated specimen shown in Plate 43 is with some doubt referred to this species, the thickness of axis and leaf being exaggerated by the adhering silt.

As shown in a comparison of figure 4, Plate 44, with Plate 42, figure 2, which represents the smallest twigs in my collection that appear referable to *Walchia piniformis*, the leaves of *Walchia dawsoni* are much closer as well as more distinctly uncinnate. The species deserves critical comparison with Permian specimens from the Maritime Provinces.

Locality: Hermit shale, in the Hermit basin.

Walchia gracillima D. W. n. sp.

PLATE 44, FIGS. 2, 3, 5, 5*a*, AND 6

Branches graceful, extremely delicate, distichous, somewhat dense, slightly plumose, foliate between the ultimate branchlets; ultimate branchlets or twigs very close, sometimes two to the centimeter in the younger parts of the branch, open nearly at a right angle or somewhat oblique, parallel, extremely slender or attenuate, sometimes reaching lengths of 10 cm. or more, 2.5 to 3 mm. wide, faintly narrowed downward near the base and tapering near the apex to a narrow rather obtuse tip; leaves 2 to 4 or rarely 5 mm. long, strongly decurrent on a slender axis, moderately close to rather distant, very oblique, rarely at more than 40° to the axis, often nearly erect and arched outward slightly in the middle portion of the axis and below the apex which bends inward a little, long-linear-lanceolate, often appearing widest at or above the middle, and narrowed rather rapidly above to the acute or slightly obtuse ventrad curved apex.

This species is remarkable not only for its delicacy of structure and for its grace, but also for the relative rigidity of the very slender, apparently attenuate twigs, as indicated by the parallelism of the latter as they drifted into the silt-laden water. Some of the incomplete twigs are over 10 cm. in length, and it is probable that the largest considerably exceeded this. The general aspect and atti-

tude of the twigs is shown in Plate 44, figures 5 and 6. The former shows portions of two branches lying at different angles. The leaves shown twice the natural size in figure 5*a* are unusually straight and slender. The characteristic angle and spacing of the twigs is seen in figures 3 and 6, the former of which embraces a fragment of an axis or limb. Neither the spacing nor the width of the ultimate branchlets in this species differs appreciably among the great number of specimens seen.

Some of the broader twigs are shown in figure 6. On the other hand, the leaves shown in figure 2 exhibit an exceptionally strongly arched and open phase of the foliation. Near the bases of some of the ultimate branchlets the leaves are relatively broader, more distinctly lanceolate and somewhat shorter.

The leaves, imperfectly shown in the photographic enlargements, are in their slenderness and obliquity comparable to the plant originally figured by Dawson [1] as *Araucarites gracilis,* though the latter is much more robust and has much larger twigs. However, allowing for probable variation in the true *Walchia gracilis* of Dawson, it is probable that the species from the Yaki trail finds therein its closest known relative. *Walchia linearifolia* Goeppert [2] may also be compared, notwithstanding its far greater size.

Walchia gracillima is so similar in aspect, spacing, attitude and size of ultimate twigs and even in foliation to the branch figured by Zalessky [3] as *Walchia hypnoides* that I should not hesitate to apply that name to Arizona specimens, were not Brongniart's type apparently so different. The plant from the Artinsk of the Ural region seems to have leaves slightly broader a little above the base, from which point they taper to an acuminate point. Its leaves are distinctly different from those in the small twig from the upper Autunian of the Blanzy and Creusot basin figured by Zeiller as *W. hypnoides.*

The beautiful pinnate branches with graceful, slender, arching, parallel twigs is very similar to that of one of the specimens illustrated by Zeiller in an earlier publication [4] as *Walchia hypnoides.* However, as already indicated, the leaves of *W. gracillima* are relatively more distant, more slender, and more acute than in *W. hypnoides.*

Locality: Lower part of the Hermit shale. Yaki trail only.

[1] Quart. Jour. Geol. Soc. London, vol. XXII, 1865, page 146, pl. 6, f. 14.
[2] Goeppert, Foss. Fl. Perm. Form., 1865, page 242, pl. 51, figs. 9, 10.
[3] Mém. Com. Géol., n. s., livr. 176, p. 48, pl. 33, f. 5 and 5*a*.
[4] R. Zeiller, Explic. Carte Géol. France, vol. 4, 1879, pl. 176, fig. 4.

Walchia hypnoides Brongniart ?

PLATE 49, FIG. 5

1828 *Fucoides hypnoides* Brongniart, Hist. Vég. Foss., vol. 1, p. 84, pl. 9 *bis,* f. 1, 2.
1849 *Walchia hypnoides* Brongniart, Tableau, p. 71; Pilla, Tratt. geol., vol. II, 1851, p. 479, f. 255; Williamson, Rev. Sci., (2) 1875, p. 1064, f. 46; Zeiller, Expl. Carte Géol. Fr., vol. IV, 1878, p. 155, pl. 176, f. 4; Renault, Cours. bot. foss., vol. IV, 1885, p. 85, pl. 8, f. 5; Zeiller, Éléments Paléobot., 1900, p. 261, f. 186; Fritel, Hist. Nat. Fr., 24*e bis,* Pl. Foss., 1903, p. 60, pl. 14, f. 1; Zeiller, Bassin Houill. Perm. Blanzy et Creusot, Pt. 2, Fl. Foss., 1906, p. 208, pl. 50, f. 9, pl. 51, f. 1.

In this as in some other species of *Walchia,* more attention has in general been given to the aspect of the foliate branch than to the characters of the leaves themselves. Accordingly, we find specimens with outward arching, uncinnate, acute leaves placed in the same species with specimens having appressed nearly flat obtuse leaves.

The fragment from the Hermit shale is shown twice the natural size in Plate 49, figure 5. The solitary example of this form in the collection agrees so fully in characters with the apical twig illustrated by Zeiller[1] from the Bassin of Blanzy and Creusot that I regard it as probably proving the presence in the Permian of Arizona of a form found also in the upper Autunian of France.

Locality: Lower part of Hermit basin, near the Yaki trail.

Ullmannia Goeppert, 1850

Monogr. Foss. Coniferen, p. 185

Ullmannia frumentaria (Schloth.) Goeppert

PLATE 46, FIGS. 1-6; PLATE 48, FIGS. 1, 1A, AND 2; PLATE 51, FIG. 7

1820 *Carpolithes frumentarius* Schlotheim, Petrefactenkunde, p. 419, pl. 27, f. 1.
1850 *Ullmannia frumentaria* (Schloth.) Goeppert, Monogr. Foss. Conifer., p. 189, pl. 21, f. 1-3; Geinitz, Leitpfl. Rothl. Zechst. Sachsen, 1858, p. 23, pl. 1, f. 7; Geinitz, Dyas, pt. 2, 1862, p. 155; Hellmann, Paleontogr., Suppl., vol. 1, 1862, p. 14, pl. 5; Goeppert, Palæontogr. vol. 12 (Foss. Fl. Perm. Form.), 1865, p. 228, pl. 46, f. 1-3; Schimper, Traité Pal. Vég., vol. 2, 1870, p. 312, pl. 76, f. 4; Saporta, Monde Pl. Appar. Homme, 1879, p. 186, fig. 15 (3-4); Roemer, Lethæa Geogn., vol. 1 (Palaeozoica), 1876, pl. 60, f. 2, text, 1880, p. 253; Geinitz, Mitth. K. Min. Geol. Praehist. Mus. Dresden, vol. 3 (Nachtr. z. Dyas, 1), 1880, p. 20, pl. 3; Solms-Laubach, Paleont. Abhandl., vol. 2, No. 2, 1884, p. 82 (4), pl. 12 (1), f. 2, 4, 7-9, pl. 14 (3), f. 2, 5, 7; Renault, Cours. bot. foss., vol. 4, 1885, p. 91, pl. 8, f. 11; Walther, Geol. Heim. Thüringen, 3d ed., 1906, p. 58, text-fig. 35; Zeiller, Bass. houill. perm. Blanzy et Creusot, pt. 2, Fl. Foss., 1906, p. 219, pl. 50, f. 11-13; Schuster, Geogn. Jahresb., vol. 20, 1907 (1908), p. 232, pl. 10, f. 18; Gothan, Entwick. Pflanzenw., 1909, p. 64, f. 34*c;* Czarnocki and Samsonowicz, Rezpr. Wydz. Mat. Przy. Akad. Umiej., vol. 13, B, 1913, p. 278, pl. 17, f. 4-6*a,* 9; Seward, Foss. Pl., vol. 4, 1919, p. 298, text-fig. 750*a-c;* Gothan and Nagel, Glückauf, Essen., vol. 56, 1920, p. 105, pl. 1, f. 3; Gothan and Nagel, Jahrb. k. Preuss. Geol. Landesanst., vol. 42, 1921 (1922), p. 445, pl. 5, f. 3, pl. 7, f. 3-4; Kraüsel, Senckenb. Wiss. Mitth., vol. 5, 1923, p. 86, pl. 4, f. 7-8.

[1] R. Zeiller, ***Bassin Houill. Perm. Blanzy et Creusot,*** pt. 2, Fl. Foss., 1906, pl. 51, f. 1.

Branches coarse, subdividing very infrequently and irregularly, thick, fleshy; ramules retaining their leaves at least until as much as 1 cm. in diameter; leaves spirally arranged, slightly irregular, sometimes a little lax, with very fleshy, protuberant, decurrent bases which leave broadly diamond-shaped traces on the larger twigs, linear-lanceolate, acute, very open or oblique except on the smaller ultimate twigs, where they are usually very oblique at the base, decurrent, becoming thin and often lax in passing upward, arching outward somewhat, and more or less distinctly uncinnate, round-convex dorsally, with relatively narrow persistent midrib, concave ventrally above the base, rugose by fine rows of round-protuberant scale-like cells, each marked by a very short hair, and sparsely clothed with short, sharp, rigid spines; cones large, terminal, 5 to 8 cm. long, 2 to 3.5 cm. wide, composed of rather loosely placed, open or somewhat oblique narrowly lanceolate, acute bracts which are generally broader and longer than the large leaves, narrowed at the cuneate base or stalk, which is much thickened, and dilated about 3 to 6 mm. from the point of attachment into a narrowly lanceolate-triangular, concavo-convex upward-curving acute blade; seeds small, oval-round, about 2.5 mm. long, apparently supported in the dilation at the base of the bract.

As shown in Plate 46, figure 5, the protruding leaf bases are relatively thick and fleshy and sometimes appear dilated. Lack of rigidity of the leaves is observed in portions of all specimens examined. The leaves are traversed by a relatively narrow, thin midrib, dorsally rounded and persistent, though tapering, while becoming lax, to the apex. An interesting feature of the midrib is its downward prolongation as a slender strand through the thickened leaf base and far within the border of the thick fleshy cortex of the stem, where it bends down to join the axis. The thick zone of relatively soft and probably lacunose tissue of the stems and leaf bases of this tree suggests the Pteridosperm and the Lepidophyte.

The lamina on either side of the midrib, though coriaceous, is evidently flexible and readily subject to deformation. It is faintly—sometimes rather distinctly—lineate in the longitudinal sense, the lineation corresponding to rows of short or squarrose, round-convex cells, each of which is marked by a minute punctation, the attachment of a short papilla, thus giving the leaf a faintly pubescent covering. Besides the apparent pubescence, the leaf is marked on both ventral and dorsal sides by short, rigid sharp spines, varying somewhat in length, but generally less than 0.5 mm. long. They are not oriented parallel to the axis of the leaf, and were evidently upright or nearly vertical to the lamina. The bases of these spines are marked by pits which are particularly distinct along the midrib or median nerve, where, in some places, the impression suggests the presence of a small gland at the base of each spine. The shape and mode of attachment of these spines, some of which are rather long, and the occurrence of considerable numbers of detached spines in the

matrix, suggest that they were readily removed by abrasion in a way comparable to the detachment of the spines of certain cacti. The molds of some of the shorter spines are seen pressed against the lamina. A notable feature is the occurrence of this xerophytic character in lesser development on the surfaces of the bracts of the cone.

The large protruding leaf bases are shown partly in profile, Plate 46, figures 4 and 5. Some of them have the aspect of having supported sporangia, like those of a Lepidophyte, and in one specimen there is a suggestion of a ligular pit.

In many instances the leaf blade appears to be prolonged in a slender, almost filamentous, branching, lax proliferation. Also, some of the specimens seen in profile seem to exhibit indications of slender, fragile, pinnately but sparsely remote appendicular growths suggestive of soft delicate chaffy scales of branching habit. Clearer evidence of the nature, origin and function of these indicated growths is greatly to be desired. That they are not, however, in all cases the mere result of laceration of the lamina, appears to be proved by the presence in the slender appendage of a central strand or nerve. The appendages, if such they are, seem to have been borne here and there very sparsely on both sides of the leaf and at the apex as well as near the base. I regard them as a xerophytic development. It is much to be hoped that better preserved material will serve for their more satisfactory delineation as well as their conclusive interpretation.

In Plate 46, figures 4 and 5, are shown leaves which fork near the apex in two relatively narrow divisions, apparently in the manner characteristic of *Buriadica,* described by Seward and Sahni [1] from the Karharbari beds of India. In fact, if the latter genus is well founded, on this sole character, the Arizona specimen should probably be included under that name. At all events this seems to furnish another connection between the Hermit flora and the Gondwana flora. The leaves of the series of specimens from the Lower Gondwana flora illustrated by Feistmantel [2] as *Voltzia heterophylla,* with which our material appears to agree, have been reexamined by Seward and Sahni, and found to reveal bifurcation.

It is probable that the appearance of slender, relatively rigid, narrow, open leaves or bracts, sometimes considerably longer than the normal leaf and located seemingly between the leaf bases, as viewed in several specimens, is due either to the midribs of macerated leaves or of leaves seen only in profile. Curiously enough, however, they often appear more rigid than the complete leaf. The specimens do not, I believe, justify the conclusion that the leaves of this tree

[1] Mem. Geol. Survey India, n. s., vol. VII, No. 1, 1920, page 12. pl. 2, f. 20-25*a*.
[2] Mem. Geol. Surv. India, n. s., vol. III, pt. 1, 1879, pls. XXII-XXV.

are polymorphous and that such polymorphism is seen even in the cones, though it would not be surprising if the discovery of better preserved material, especially as carbonized remains, in a more fine-grained matrix, would show such polymorphism.

Cones without doubt referable to the species here described are shown in Plate 46, figures 2, 3, and 6, and Plate 48, figures 1, 1*a*, and 2, the last two being twice enlarged. Detached bracts, probably from similar cones, are seen in figure 1 of Plate 46 and figure 7 of Plate 51. More or less complete bracts still attached are shown in both photographic enlargements. In one of our specimens, Plate 48, figure 2, the dilated leaf base or foot-stalk of the leaf appears much thicker than the blade or bract proper. In this specimen the blade is torn and the leaf base partly detached and pushed back. Several seeds are seen indistinctly in Plate 48, figure 2. The aspect of the mold of the compressed seed suggests that one or more seeds are placed on the dilated foot-stalk thus suggesting the Lepidophyte, rather than within the base of the blade. I am inclined to believe that at least one ovule was borne on either side of the axis on the ventral lobes of the stalk.

The cones in Plate 48, figure 1, and Plate 46, figure 2, are comparable to that shown by Zeiller in his *Flora of the Carboniferous and Permian Basins of Blanzy and Creusot* (Pl. 50, fig. 5) as *Walchia piniformis.* The French specimen belongs, I have no doubt, to *Ullmannia frumentaria,* which occurs at the same locality and in the same beds.

The specimens, about a dozen in number, representing this species, were more or less macerated before burial, with some deformation, in the sandstone, so that they present a baffling range of more or less indistinct features, the satisfactory elucidation of which must await the discovery of better material from this or some other region.

Localities: Near the base of the Hermit, near the Hermit trail, in the Hermit basin, and to the west of the Bright Angel trail, below the El Tovar.

Voltzia Brongniart, 1828

Dict. Sci. nat., vol. LVII (Prodrome), p. 112 (108)

Voltzia dentiloba D. W. n. sp.

Plate 51, Fig. 5

Scales narrowly cuneate, the lower two-thirds tapering slowly downward, shallowly grooved ventrally, round-carinate dorsad and thick, with slightly concave margins and dilated abruptly at the base of the upper third, which is palmately or flaringly divided into 5 to 12 short, ovate-triangular, dorsally convex, carinate, slightly acute, tooth-like, thick, rigid lobes, which are ventrally somewhat concave, especially toward the base,

and apparently creased upward; middle lobes longest and largest, the lateral being shorter, narrower, and apparently less developed; the larger lobes seeming each to bear an ovate or long-oval seed, nearly as wide as the lobe, just above the base, or the lobe is marked by an oval depression above the center of which is a small round scar.

The above-described species is represented by but two scales, both rather obviously belonging to a cone. Neither is, however, so complete or distinct as is to be desired. Figure 5 of Plate 51 presents a ventral view in which the lower part of the scale is shallowly grooved near the middle and the teeth are ventrally concave and slightly incurved at the top. The shorter or weaker lateral lobes of the bract are perhaps abortive.

In another specimen the scale, in dorsal view, has round-convex, narrow, oval-triangular and distinctly acute teeth. Strong nerves emerge in passing up the lower part of the bract, apparently forking, fern fashion, near the dilation of the scale, to furnish a small nerve for each tooth.

This species has smaller bracts with narrower bases and more acute teeth than those of *Voltzia heterophylla,* though the scales of the latter sometimes have rather sharp teeth, as is illustrated in the specimen shown by Renault.[1] The aspect of the scales is slightly suggestive of *Cheirostrobus* and *Swedenborgia.*

Locality: Lower part of the Hermit near Hermit Trail, Hermit Basin.

Voltzia sp.

PLATE 50, FIG. 5

Among the material from the Hermit shale is the impression of a single scale shown in Plate 50, figure 5. There being no other specimens to illustrate other forms of the scale, which in this genus is usually highly variable, I merely call attention to its probably unquestionable reference to *Voltzia* and to its similarity to some of the specimens illustrated by Geinitz from the copper shales of Trebnitz near Gera[2] as *Voltzia liebeana* Geinitz.

The species is quite distinct from *Voltzia dentiloba* described in the foregoing section, which may be recognized by its semi-acute lobes, apparently pitted at their bases, and the slender shank of the graceful elongated, concavely bordered scale.

[1] *Cours de Botanique Fossile,* vol. 4, 1885, pl. 13, fig. 4.
[2] H. B. Geintz, *Nachtrag zur Dyas,* I, 1880, page 26, pl. 5.

TAXALES

Paleotaxites, new genus

Paleotaxites præcursor D. W. n. sp.

PLATE 49, FIGS. 1 AND 3; PLATE 50, FIGS. 1, 2, 2*a*, 6, AND 6,; PLATE 48, FIG. 3; PLATE 45, FIG. 4

Branches linear, tapering to acute apices, very compact and bushy, especially when young, densely clothed with close, rigid, slender, relatively short, spirally arranged twigs, in several, probably as many as six, rows in the longitudinal direction, at angles approaching 45° to the axis, which is provided with leaves much broader and much longer than those on the ultimate branchlets; twigs or ultimate branchlets slender, very close, 2.5 to 6 mm. wide, becoming elongated-linear in later states, hardly tapering, and obtuse at the apices; leaves very small, spiral, compact, relatively broad at the thick base near which they are rhomboidal in cross-section, squammiform, 2 to 4.5 mm. long, broadly angular-carinate dorsad, slightly convex on either side, more prominently and narrowly carinate ventrad, and slightly concave on either side, flaring very open in the lower part, becoming rounded dorsally, and curving rapidly upward at about two-thirds of their length, and, while all the time narrowing very rapidly, bent slightly inward at the rather blunt point; buds at the ends of the twigs slightly wider, more compact, oval, and, in length, about 2.5 times the breadth of the twig, with compact imbricated leaves developing substantially as in the lower portion of the twig; fruit oval-obovate, about 9 mm. long and 5 mm. wide above the middle, borne apparently just beneath the apex of the short twigs, or possibly terminal, leathery, becoming hard and somewhat brittle, without ornamentation, so far as observed, at the apex, and adherent to several scale-like rudiments of leaves at and a little above the base.

The beautiful conifer here described is one of the effective contributors to the distinctly Mesozoic facies of the Hermit flora. Plumose in density but dwarfed and rigid in the details of its twigs and leaves, it constitutes an unique species. The compactness of the spirally pluriseriate twigs in the young branches is well shown both in Plate 50, figure 6, and Plate 49, figure 3, in both of which the points of entrance into the rock of the pluriseriate twigs not lying in or near the bedding planes are plainly visible. The very small, blunt, clawlike leaves are shown more clearly in figure 6 of Plate 50, and in figure 6*a*, which enlarges, twice the natural size, some of the leaves and the terminal buds.

An older branch with larger and more elongated twigs is seen in Plate 49, figure 1. Here the branch though obviously polyseriate is flatter than the more plumose, younger branchlets. The specimen is somewhat eroded. Plate 49, figure 3, rather dimly shows a part of an elongated plumose branchlet, over 20 cm. in length, which is preserved on the slab.

One of the specimens unmistakably belonging to this species is remarkable for the presence of the remains of its large, partially collapsed, fruits attached at or nearly at the ends of each of several of the lateral twigs. Portions of five of these fruits are seen obliquely placed at the ends of as many twigs in a segment of a branchlet 12 cm. long. One of the fruits in the lower part of this specimen, Plate 50, figure 1 (twice the natural size), shows by its wrinkles the leathery texture of its hard outer envelope. Scale-like rudiments of leaves are seen at its base. Another seed on the twig to the left is poorly shown in the photograph. Portions of two of the fruits, borne by adjacent twigs higher in the branch are seen, twice the natural size, in Plate 50, figure 2, where we observe, adhering to the base of the seeds, several rudimentary scales, two of which, on the right, have free apices turned outward away from the seed. In this specimen, shown four time the natural size in figure 2*a*, the thick wall of the seed, which appears to have been somewhat globular, elongated obovately in the longitudinal direction, seems to have had a brittle outer coat or aril which is crushed. The scale-like protuberances from the lower part of this fruit are generally in ovate patterns, small but variable in size, apparently imbricated spirally from its point of attachment. In these respects the fruit of *Paleotaxites præcursor* is comparable in aspect to the fruit of *Juniperus* or *Tumion*. On the other hand, the form and disposition of the leaves of the tree are somewhat suggestive of the cedar.

In the specimen shown in Plate 45, figure 4, the twigs had become plastered with mud slime and were later partially washed by current movement before embedding in relatively coarse sand. The result is the flattening of several of the twigs on the bedding plane. The squammose aspect of the dorsally convex surfaces of the leaves is, however, seen in the lower part of the photograph, which has not been retouched.

Among Permian plants of other parts of the world, fertile forms inviting comparison with *Paleotaxites* in a broad systematic sense are found in the twigs from the cupriferous shales of Saxony described by Geinitz[1] as ultimate fertile shoots of *Voltzia liebiana;* also the naked, rounded, upright seeds borne on the sides of the cone and apparently axillary in position, separately described by Geinitz as *Cyclocarpon eiselianum* are strongly suggestive of the fruits of the Grand Canyon genus. Though the Saxon twigs are very much larger than ours, and, if the correlations of the parts of the plant are correct, belong to a plainly different genus, they are, however, to be taken into account, together with ours, in any discussion of the phy-

[1] *Nachtrag zur Dyas,* I, 1880, page 26, pl. 5, f. 9.

logeny or antiquity of the Taxalean conifers. In this connection mention may be made also of the presence in the Hermit flora of small *Voltzia* cone scales comparable with those figured in the same flora from the Trebnitz beds near Gera.

The naked erect fruit from the Hermit shale, reminds one of the fruit from the copper shales of Ilmenau described by Goeppert[1] under the name *Ullmannia frumentaria.* The associated foliage is, however, quite different.

Paleotaxites præcursor is easily distinguished from *Walchia* by its spirally arranged twigs, and though the isolated fragments closely resemble those of *Walchia gracillima,* they are readily separated by the angular, large-based, rapidly tapering, rigid, tooth-like leaf.

Localities: The species was found by Dr. L. F. Noble in the lower part of the Hermit shale in the Hermit basin (Lot 7880 of the collection of the Geological Survey). I found specimens near Dripping Spring in the same basin, and near the Yaki trail. It is rare.

Taxites Brongniart, 1828

Dict. Sci. Nat., vol. LVII (Prodrome), p. 111 (108)

Taxites ? sp.

Plate 49, fig. 6

To this genus I tentatively refer an impression which is doubtless gymnospermous and which appears to represent a bud or twig crowned with linear-lanceolate, rather obtuse, ventrally convex leaves, each of which appears to be traversed by a central nerve very indistinctly shown in the impression.

The poor preservation of the specimen does not appear to justify further consideration in this place, but it is hoped that by illustrating this fragment attention may be called to the need for securing material sufficient to reveal the characters and relations of the plant. It appears to be different from any gymnosperm yet found in the Permian of North America.

Locality: Lower part of Hermit shale, Hermit basin.

PINALES ?

Brachyphyllum Brongniart, 1828

Dict. Sci. Nat., vol. LVII (Prodrome), p. 113 (109)

Brachyphyllum arizonicum D. W. n. sp.

Plate 48, Fig. 4

Branches distichous, with large, scale-like, very oblique leaves, densely clothing the penultimate axis, and, probably, divisions of higher rank; ultimate divisions or twigs close, about 14 mm. distant in the branchlets,

[1]Foss. Fl. Perm. Form., 1864, page 228, pl. XLVI, f. 4.

very open, parallel, narrow, straight, relatively rigid and opposite; leaves very short, close, obliquely spiral, open at about 45° to the axis, with very broadly deltoid, dorsally convex, hardly carinate bases, about half the width of the twig, narrowing rapidly with slightly concave borders, while becoming carinate and curving upward, to a short, slightly inward-curved, blunt apex at about one-third the length of the leaf next above.

As shown in Plate 48, figure 4, this species, of distinctly Mesozoic aspect, is conspicuous for the broadly triangular leaf bases which are fully half the entire width of the twig and stand out obliquely in loose imbrication. The leaf narrows very rapidly, while curving upward and becoming more prominently carinate, to a rather blunt inward bent, beak-like apex. The ultimate branchlets are seen to be open, close and parallel, as in *Walchia,* and the parent axis is clothed with oblique overlapping scales, some of which are much broader as well as larger than those of the twigs.

The figured specimen of *Brachyphyllum arizonicum* deserves comparison with the specimen from the copper sandstones of the Donetz basin illustrated by Zalessky[1] as *Walchia filiciformis* (Schloth.) Sternberg. I am, however, obliged to question the identification, for *Walchia filiciformis* differs not only from the Arizona specimen but possibly from the Donetz specimen by its very flaring slender leaves, which turn upward far from the axis, so that the twigs are relatively wide.

Locality: Lower part of Hermit shale near Dripping Springs, Hermit basin.

Brachyphyllum tenue D. W. n. sp.

PLATE 45, FIGS. 1, 2 2*a* AND 3

Branches very slender, 2 to 3 mm. wide, slightly rigid, but gently curving and tapering very gradually or, in the ultimate divisions, almost imperceptibly, while repeatedly forking distantly and at a very narrow angle in the peripheral portions; ultimate divisions or twigs linear-elongated, about 1.5 to 2.25 mm. wide, generally slightly curved, obtuse; leaves very small, generally obscure, spirally arranged, very closely appressed, close, overlapping for nearly half their length, broadly attached, ovate, about 2 mm. long, the borders converging, nearly straight, in the upper part dorsally round-convex, medially carinate, especially near the top, and terminating in a short, thickened, narrow acute spine.

I know no type among Paleozoic gymnosperms that approaches so closely to the branchlets shown in Plate 45, figures 1, 2, 2*a* and 3 as that from the Newcastle Permian beds of New South Wales, Australia, and other Gondwana lands described by Feistmantel[2] and

[1] Mém. Com. Géol., n. s., livr. 178, 1927, pl. 33, f. 6.

[2] O. Feistmantel, *Foss. Flora Australiens,* Palæontographica Suppl. 3, Hft. 3, 1878, pl. VII, f. 3-6; Mem. Geol. Surv. N. S. W., Paleont., No. 3, 1890, page 162, pl. 15, f. 4, pl. 22, f. 1, 2.

others as *Brachyphyllum ? australe.* Both plants appear to have the same habit of growth of the twigs, and similarly closely appressed, short-lanceolate acute leaves. The branches and twigs in our specimens are very much more slender, being less than half the width of the Gondwana plant, and the leaves are so small and closely appressed against the axis as to be hardly visible to the unaided eye. Yet the plants conform so closely in other respects as to raise a question as to whether the Arizona plant is not merely a form of the other, reduced by unfavorable environmental conditions. The specific separation of the Hermit plant is based largely on the much greater slenderness of the ultimate twigs, which branch more frequently, and on the relatively few leaves and their relatively large size.

Localities: Lower part of Hermit shale in Hermit basin, and near Bright Angel trail, below El Tovar.

Pagiophyllum Heer, 1881

Contrib. Fl. Foss. Portugal, p. 11

Pagiophyllum dubium D. W. n. sp.

PLATE 47, FIGS. 1, 3, 4 (?) AND 5

Ultimate divisions or twigs rather close, very open, slightly irregular, sub-parallel, slender, narrow, tapering slightly proximad near the base, and distad gradually in the upper portions, with axis rather thick in the impression, as though by the collapse of a thick lacunose mesocortex; leaves distant, very broad at the base, oblique, decurrent, clavate or slightly triangular, thick, apparently fleshy, curving slightly upward or nearly straight, shorter near the base of the twig and toward the apex, tapering moderately from the base to the abruptly and bluntly rounded, or sometimes apparently truncate, apex.

The specimens in hand are not sufficient adequately to characterize this species, which, nevertheless, appears, by the disposition of the twigs and the form of the leaves, to be a distinct species. The leaves in some specimens are clavate, as shown in Plate 47, figures 3 and 5. In the original of figure 1 some of them appear acute in both dorsal view and in profile, as though a thin acute bract supported a clavate or cylindrical organ or appendage whose rounded apex extended barely beyond the apex of the bract.

The aspect of the impressions of both the axis and the leaf of the twig suggest a thick zone of lacunose tissue for water storage.

The provisional reference of the plant to the form genus *Pagiophyllum* is non-committal as to the systematic relations of the species, which require validation.

The general aspect of the smallest fragments suggests the specimen from the *Walchia* sandstone in the Brives basin figured by

Zeiller [1] as *"Sphenopteris ? sp."* The latter is distichous with very oblique pinnules.

For the present *Pagiophyllum dubium* may be distinguished by its very short, thick, oblique, and more or less distinctly clavate, distant leaves, which are abruptly rounded or round-truncate at the apex.

Locality: Base of Hermit shale; found only in Hermit basin.

FRUITS, OF UNCERTAIN AFFINITIES

Cyclocarpon Goeppert and Fiedler, 1857

Nova Acta Acad. Caes. Leop. Car., vol. XXVI, p. 291

Cyclocarpon angelicum D. W. n. sp.

PLATE 50, FIG. 7

Ovate seed about 12 mm. long and 9 mm. wide, with very narrow, finely lineate border impression of vascular coverings which are a little denser at the slightly apiculate top, and at the bottom, which is slightly rounded on either side of the point of attachment.

The seed shown in natural size in Plate 50, figure 7, was probably originally round in cross-section. It appears to have had an outer fibrous, and a thinner, more faintly vascular envelope, both now flattened and forming a border zone, about the nutlet. It is unlikely that the outer test was rigid.

The figured specimen may be compared with some of the seeds illustrated by Weiss [2] as *Rhabdocarpus ovoideus* from the Permian of Saxony. These seeds are of the type correlated by Grand'Eury [3] with the fronds of *Callipteris conferta.* Fruits similar to *Cyclocarpon angelicum* or that next to be figured as *Carpolithus* sp. may have been borne by *Supaia* which, as already emphasized, not only is closely related to *Callipteris,* but is probably derived from it. In fact if *Cordaites* and the Neuropterid and Sphenopterid groups of Pteridosperms are absent from the Hermit, as now seems to be the case, there would appear to be no plants present except *Supaia, Callipteris,* and possibly *Tæniopteris,* which could have borne these *Cyclocarpon* types of seeds. The fruit of *Psygmophyllum,* a genus possibly present, is unknown.

In general, seeds are unaccountably rare at those localities where the Hermit shale has been searched for fossil plants. This is the more remarkable since, with fluviatile deposition, including the presence of occasional pools along the arroyos, the conditions should have been favorable for the accumulation of windblown or drifted seeds

[1] *Bassin houill. et Perm. Brive,* pt. 2, Fl. Foss., 1892, pl. 1, f. 6.
[2] Weiss, Foss. Fl. Jüngst. Steink. u. Rothl. Saar-Rh. Geb., 1872, pl. XLIII, f. 18, 1920.
[3] C. Grand'Eury, Comptes Rendus, Acad. Sci., vol. 143, 1906, page 664.

in considerable numbers. Doubtless at some outcrop yet to be examined seeds will be abundant.

Locality: Near base of the Hermit shale, in the outcrop west of the Bright Angel trail, below El Tovar.

Cyclocarpon sp.

PLATE 49, FIG. 4

The seed shown, twice the natural size, in Plate 49, figure 4, answers in a general way the description of a group of small forms referred by authors to *Cyclocarpon* and *Carpolithes.* Such seeds occur in most collections of plants from the middle Permian and the base of the Zechstein.[1] Some of them may be seeds of *Nœggerathiopsis* or *Cordaites.* Similar forms have been correlated by Grand'Eury,[2] on convincing circumstantial evidence of conditions of occurrence, with *Callipteris,* and specifically with *C. conferta.*

The seed here illustrated lies in the axil of a pinna of *Yakia,* and may have been attached to, but is not actually proved to be in union with the rachis. Therefore, though it is such a seed as would be expected in a member of the *Callipteris* group, it can not yet be regarded as demonstrated to belong to the *Yakia* on which it lies.

The seed now flattened to lenticular shape has a very narrow but well-defined vascular border, and has a very small acute apical beak.

In passing it may be noted that the photograph suggests the former presence of similar seeds in the axils of other pinna of the specimen, an aspect that is not, however, so noticeable in the specimen if it is illumined from other directions.

Locality: In coarse, gnarly, current-rippled, sandy shale from the lower part of the Hermit shale in the Hermit basin.

Carpolithus sp.

PLATE 50, FIG. 3

Oval, flat, very faintly apiculate seed 8 mm. long, 6 mm. wide, and bordered by a very narrow ring including apparently two very thin vascular envelopes, the width of the ring being about 0.5 mm. except at the top, where it is slightly and rather broadly extended upward.

The specimen photographed in Plate 50, figure 3, is the only one of this form found in the collection. The preservation of the seed leaves much to be desired. Probably a pollen chamber was present

[1] See C. E. Weiss, *Foss. Fl. Jüngst. Steink. u. Rothl.,* Saar-Rh. Geb., 1872, pl. XVIII, f. 1-30.

[2] C. Grand-Eury, Comptes Rendus, Acad, Sci., vol. 143, 1906, page 664.

in the slightly dilated top. A small round body in the upper part of the seed may represent the archegonia. Traces of the inner integument are very faint.

Similar seeds from the Permian have been described as *Cyclocarpon.*

Locality: Lower part of the Hermit Trail, Hermit basin.

Eltovaria new genus

Eltovaria bursiformis D. W. n. sp.

Plate 50, Fig. 4

Purse-shaped envelope, probably of fructification, composed of thick leathery lamina, apparently a modified leaf, longitudinally folded in transversely oval or rhomboidal form, the longer, transverse axis about 4 cm. long, the vertical about 2.5 cm., broadly round at the ends with rounded margins, strongly convex though flattened and partially collapsed, and marked by coarse vertical ribs; lamina thickest at the basal angle, at which the envelope is thicker; contents of the envelope apparently three seeds, round in profile, situated near the thickened border; structural details unknown.

The structure and nature of the fossil described above are uncertain, but there is little doubt that it represents a leaf modified to serve as envelope for some form of fructification. In texture the leathery envelopes suggest a leaf of *Tœniopteris* or *Supaia,* and the fern-like nervation traversing the very coarse ribs (about 11 nervilles to one centimeter) also suggests *Tœniopteris.* I am accordingly disposed to regard it as belonging to that genus, and as borne either on the petiole below the blade or on a special stalk. However, the nerves are nearly twice as distant as in *T. eckhardti* and even farther apart than in some of the *Tœniopteris* forms from the Oklahoma-Texas Permian, referred to *T. abnormis.* Apparently the envelope was attached along a portion of the lower border. Whether the leaf or bract formed a complete envelope is not shown.

As indicated in the photograph, Plate 50, figure 4, there appear to be three roundish bodies, now collapsed, in the envelope. Whether these are ovules, sporangia or pollen-bearing discs remains to be seen, but it is to be noted that the wall of the ovuliform body evidently was thick. Unfortunately the sandy nature of the matrix and the absence of carbonized residues permit no dissection or maceration treatment.

Eltovaria is slightly suggestive of the rolled scale fronds from the lower Gondwana of India and Australia ascribed by Walkom [1] and Zeiller [2] to *Glossopteris.* On the other hand, a distinct analogy in origin and structure is, I believe, found in the inrolled fertile leaves

[1] A. B. Walkom, Queensland Geol. Survey, Pub. No. 270, 1922, page 13, pl. 1, f. 6-8.
[2] R. Zeiller, Paleont. Indica, n. s., vol. II, No. 1, 1902, pl. III, f. 6-8.

from the upper Permian of Oranetz, Russia, described by Schmalhausen at *Vertebraria (?) petschorensis.*[1]

A specimen of *Eltovaria* is seen partly exposed in the upper left corner of the rock fragment containing portions of *Supaia linearifolia,* illustrated in Plate 23, figure 1.

Since the fossils here described seem to have definite configuration and characters, geographic distribution and stratigraphic significance, they should receive systematic designation. The name *Eltovaria*[2] is non-committal as to systematic classification and may give place to some older established name when the nature of the fossils is more fully understood, or their organic union with some other previously known plant is discovered.

Locality: Lower part of the Hermit shale on Bright Angel Trail, below El Tovar, and in Hermit basin.

Gymnospermous ament

Plate 51, Fig. 6

The small fragment photographed as figure 6 in Plate 51 appears to represent a poorly preserved ament, probably belonging to a gymnosperm. The specimen was somewhat abraded before burial and the matrix is so gritty as to offer little detail. Apparently, however, the flowers consist of four or five stamens clustered about a very slender pedicel which leads to a rather delicate and now crinkled axis.

ANIMALS

VERMES?

Scoyenia new genus

Scoyenia gracilis D. W. n. sp.

Plate 4, Fig. 3; Plate 5

Slender ropelike remains, probably molds, of undetermined length, in half relief, or somewhat flattened, linear and often curved, 2.5 mm. to 5 mm. in diameter, densley clothed with more or less closely appressed, linear-lanceolate dorsally convex, tapering, acute, scarcely rigid, bract- or leaf-like appendages, which are sometimes free above the middle but without indication of structure.

Several fragments of thinly and evenly bedded shales are, like the small slab shown in Plate 4, figure 3 (twice enlarged in Plate 5), strewn with slender curved bodies in semi-relief, having the superficial aspect of molds of some moss-like organism. Among plants they

[1] J. Schmalhausen, Mém. Acad. Imp. Sci. St. Pétersb., 7th ser., vol. XXVII, No. 4, 1879, page 53, pl. VII, figs. 14-18.

[2] In common American reference to the hotel at Grand Canyon station the Spanish article is made a part of the name—e. g., the El Tovar Hotel.

suggest a lycopod, like *Selaginella.* There is no room for doubt that these molds are of the same nature as those described by Zeiller[1] from the basin of Brive as "animal trails" and again illustrated from the Permian of Thüringia by Potonié,[2] who compares them with *Spongillopsis dyadica* Geinitz. At both of the European localities we have also vertical molds which in the French specimens are plainly the centers from which the moss-like trails spread out on the bedding planes. In the fragments in hand from the Hermit shale, similar vertical molds are not distinctly connected with the slender rope-like remains, though some of them are rather plainly associated with worm borings of the common aspect, also present on the surface of the shale. Nevertheless, I am disposed to believe that the fossil is the mold of a boring, though it is difficult to explain the imbricated, sometimes divergent appendages.

The specimen described by Zeiller is republished by Fliche,[3] who discusses somewhat at length the nature of the organisms represented and concludes that the fossils represent sponges. Notable features of the Hermit type are the absence of bifurcation, although the molds vary somewhat in size, and the apparent penetration of one mold by another. In the latter case the appendages of the penetrated mold appear to rest undisturbed against the penetrating mold. As in other fossils in the Hermit shale, no trace of carbonaceous residue remains. Therefore, the actual nature of these fossils is still doubtful. However, whatever the organism responsible for these trails, which I am inclined to regard as animal, the trails present readily recognizable diagnostic characters for their classification, and appear to have stratigraphic value, as is shown by the distribution of similar species in the Permian and Triassic of Europe. Accordingly, the stratigraphic objectives of palæontology will be served by description and illustration of the fossils, which it is hoped will open the way to discovery conclusively proving their nature and origin.

The American form described above is more slender and does not appear to be fasciculate, like the illustrated European specimen. Further, it is characterized by the frequent divergence of some of the scale- or leaf-like appendages. In several of the fragments, evidently slightly abraded or water-worn, the appendages are less distinct, and present the eroded aspect illustrated by Zeiller. In one case they are even somewhat disheveled, a condition which emphasizes their leaf-like character.

[1] R. Zeiller, *Bassin Houiller et Permien de Brive,* Fasc. II, *Flore Fossile,* Études des Gîtes Minéraux de la France, Ministére des Travaux Publics, Paris, page 106, pl. 15, fig. 14, 1894.

[2] H. Potonié, *Die Flora des Rothliegenden von Thüringen,* Abhandl. d. König. Preuss. geol. Landesanstalt, N. F., Heft 9, Theil II, page 18, Berlin, 1893.

[3] P. Fliche, *Flore Fossile du Trias en Lorraine et Franche-Comté,* Bull. Soc. Sci. Nancy, vol. VI, page 30, pl. II, f. 1, 1905.

Since the fragments described and illustrated by Zeiller represent without doubt the same generic type of remains, they may, on account of their more robust proportions and their frequently radial arrangement, be designated as *Scoyenia zeilleri.* The specimen illustrated by Potonié evidently represents the same genus, and may also belong to the French species. The suspicion, developed on examination of the figures of the Thuringian example, that some of the scale-like appendages actually diverge from the axis and terminate free in the rock matrix after the fashion of some of the Hermit specimens, is probably justified.

The genus is named in honor of E. T. Scoyen, formerly Chief Ranger of the Grand Canyon National Park, now Superintendent of the Zion National Park, to whom the writer is greatly indebted for both interest and hearty cooperation.

Locality: Lower part of the Hermit shale, near the Hermit trail in the Hermit basin, and on the east of the Yaki trail below Yaki point.

Walpia new genus

Walpia hermitensis D. W. n. sp.

Plate 51, Figs. 3, 4, and 4*a*

Irregularly winding molds, varying slightly in diameter, comprising internal casts surrounded by a pavement of small, irregularly imbricated, lenticular, or lozenge-like bodies of uniform or nearly uniform size, rounded at the edges, and a little thicker at one point which is marked by a minute mammillate or slightly umbilicate scar from near which two short, very thin and shallow incisions, one on either side, diverge at an acute angle; surface of the lenticular bodies very smooth, sometimes minutely wrinkled as though leathery.

As shown photographically in Plate 51, figures 3, 4 and 4*a*, these distinctive and clearly definable fossils have the aspect of trails or borings, which, no doubt, they are. The flattened biscuit-like bodies with the slight prominences marked by minute umbilical pits are irregularly disposed, some of them being found to lie wedged against an outside wall or into the central sandstone cast, but the canal or boring is defined by the convex outward facing bodies. At first glance these bodies might be interpreted as eggs, which they strongly suggest, in their aspect, mode of occurrence, smoothness and rather leathery texture. Or they may, with better reason, I think, be interpreted as excremental pellicles discharged by some worm or related animal which ingested the fine silty material while it was still filled with organic matter. It is noted, however, not only that, proceeding in the direction of boring, the last deposited are found to lie against those farther back of them, deforming them, but also that

they truncate them. This feature harmonizes with the view that these impressions are caused by the thrust of some member or appendage of an animal, possibly a crustacean, against the wall of silt through which it was driving. However, some of the bodies are fractured or collapsed, as though they had thin brittle outer walls. On the whole, I am disposed to regard these bodies as flattened pellicles, comprising excrementa pushed against the walls of the boring.

This fossil, whose nature may be explained by additional specimens to be discovered, should have distinct stratigraphic as well as palæontologic value.

The name is taken from an Indian tribe living near the Grand Canyon.

Locality: Collected by C. W. Gilmore from the lower part of the Hermit shale near Red Top, in the Hermit basin.

EURYPTERIDEÆ

Hastimima D. White, 1908

Foss. Fl. Coal Meas. Brazil, p. 598

Hastimima sp. ?

PLATE 51, FIG. 1

The rather obscure impression shown in Plate 51, figure 1, seems to have been triangular or spadiform, smooth or even shelly in texture, and marked by distant tubercles or wart-like excrescences or short blunt spines. It appears to me to have been produced by some animal, rather than by a plant. Nothing is found in the collection that may reasonably be supposed to have borne a large spadix or a leaf base so large and of such characters. The proposal that these fossils may be the impressions of the bony plates of one of the vertebrates whose tracks are found in the shales lacks the encouragement of essential clearness of outline and structure.

On account of some resemblance in general form and a closer similarity in ornamentation to the specimens from the Permian coal measures of Brazil, described by me in 1908 as *Hastimima whitei,*[1] I tentatively range these impressions under the name *Hastimima.* The fossils from Brazil which I originally regarded as "portions of the extremities and integument of some animal, more probably saurian or batrachian," are now recognized as Eurypterid. They occur with a Lower Gondwana flora.

[1] D. White, *Fossil Flora of the Coal Measures of Brazil,* in I. C. White, Relatario Final, Comm. Estud. Minas Carvão de Pedra d. Brazil, 1908, pt. 3, page 589, pl. x, f. 1-4, pl. xi, f. 1-10.

PLATES

Note—All the plant fossils illustrated in the following plates were photographed in the laboratory of the United States Geological Survey and are in natural size unless otherwise stated. All are in red sandy shale, without carbonaceous residues or color differentiation.

Owing to the gritty composition of the matrix, the deposition of many of the leaves in stream-rippled sand or silt, and the xerophytic protection of the leaves, the nervation of the fern-like fronds is very rarely visible. In some cases the photograph shows more than is readily discerned by the naked eye.

Many of the figures are wholly without retouching; but in most of the photographs slight emphasis of midribs and margins has been given with the aid of a sharp-pointed wax crayon, which is applicable to a gloss print photograph.

PLATE 1

Slab of fine silt showing counterpart of thin slime film surface bearing a footprint which, though generically undeterminable, is referable to some primitive amphibian or reptile.

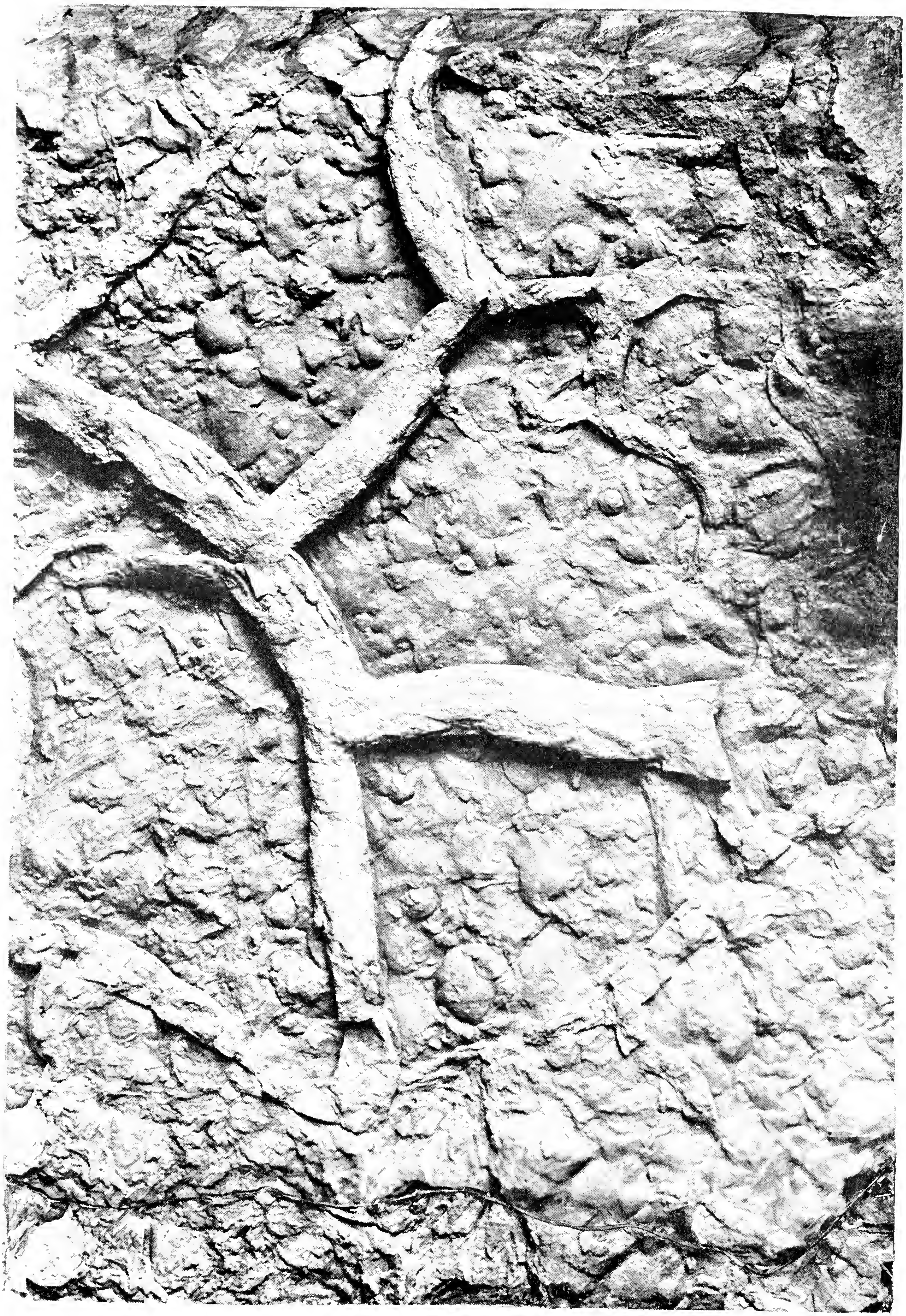
Shallow suncracking in considerable detail with incipient scaling of the surface of the silt is shown on this slab, which is slightly wavy.

Photograph submitted by C. W. Gilmore, U. S. National Museum. Specimen in collections of U. S. National Museum. Photograph in natural size; not retouched.

Sun-cracked Slime Surface, with Foot-print.

PLATE 2

Lower face of layer of silt deposited upon surface of suncracked silt, on which are impressions of hailstones. A portion of the filling of the suncracks adheres to this covering layer. From the characters of these crack fillings it would seem that following rain and hail the dried sediment had expanded and flattened slightly, with some pinching of the cracked material at the level of the surface of the deposit, which appears to have been slightly washed prior to burial. Raised crater rims are rather distinctly seen about the border of some of the hailstone impressions which, as in the case of present-day hail storms, vary in size. Photograph in natural size, not retouched.



Sun Cracks and Impressions of Rain and Hail

PLATE 3

Slime-surfaced slab in which a leaf-bearing stem of *Sphenophyllum Gilmorei* is nearly immersed. Portions of stem and leaf rising above the level of the sediment are seen to have been washed with silt and slime. Impressed in the latter numerous footprints of a supposed amphibian, *Hylopus hermitanus* Gilmore, are seen, some of them nearly obliterated, some relatively fresh and distinct. Photograph in natural size, unretouched.

Amphibian Foot-prints and Slime-covered Stem

PLATE 4

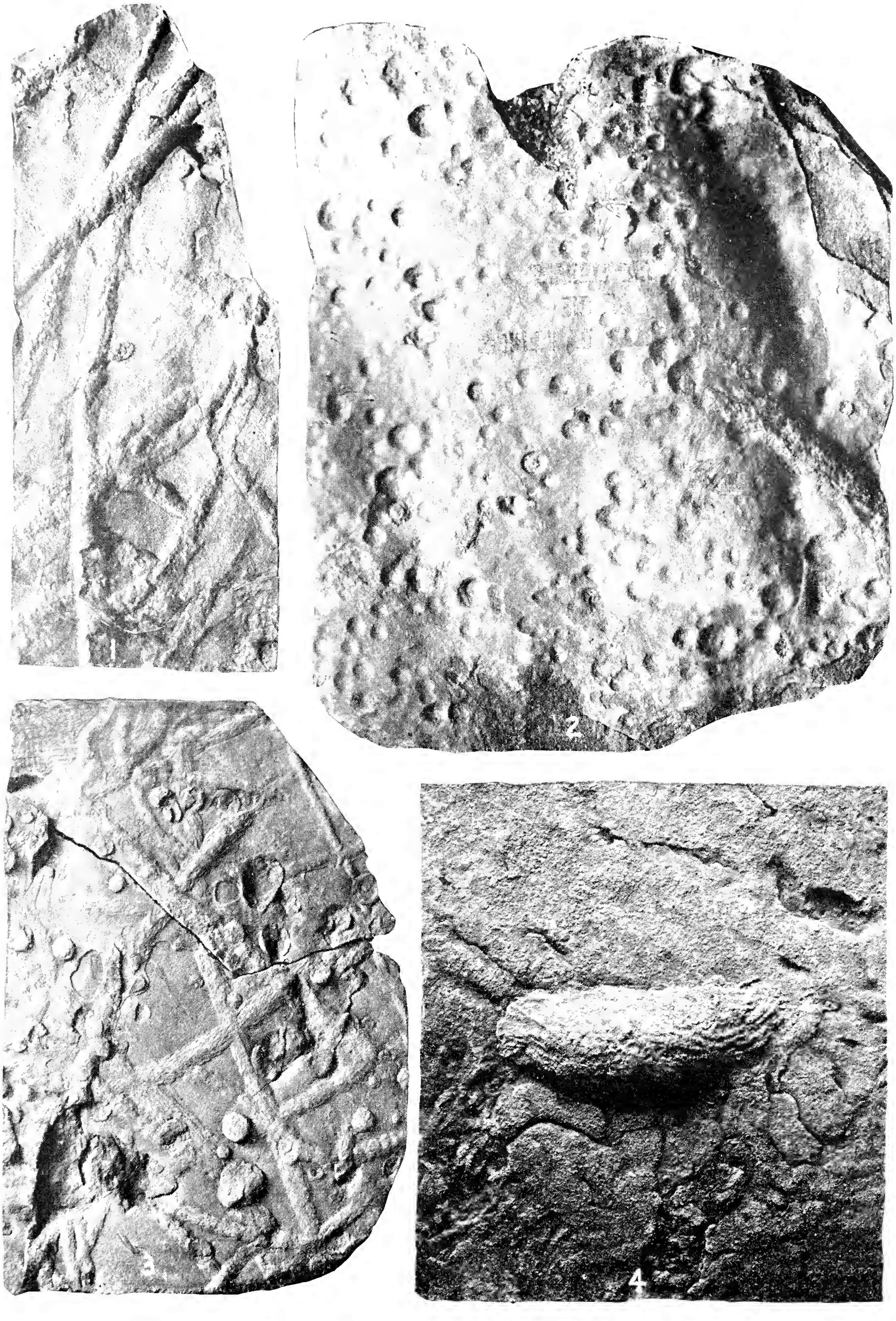
FIG. 1—Casts of supposed worm borings on the bedding plane of a ripple-marked sand.

FIG. 2—Slightly rippled surface of silt pitted by rain drops.

FIG. 3—*Scoyenia gracilis* D. W., n. g., n. sp. Plumose interlacing molds suggesting branches of densely foliate and delicate *Selaginella*. Cross-sections of vertical borings are not definitely correlated with the horizontal molds, but may be due to the same organism. The specimen is shown enlarged in Plate 5.

FIG. 4—Cast of a coprolite resting on the stream-rippled sand. This excrement, together with associated footprints and trails in the same beds, are the only evidence of vertebrate life yet found in the Hermit shale.

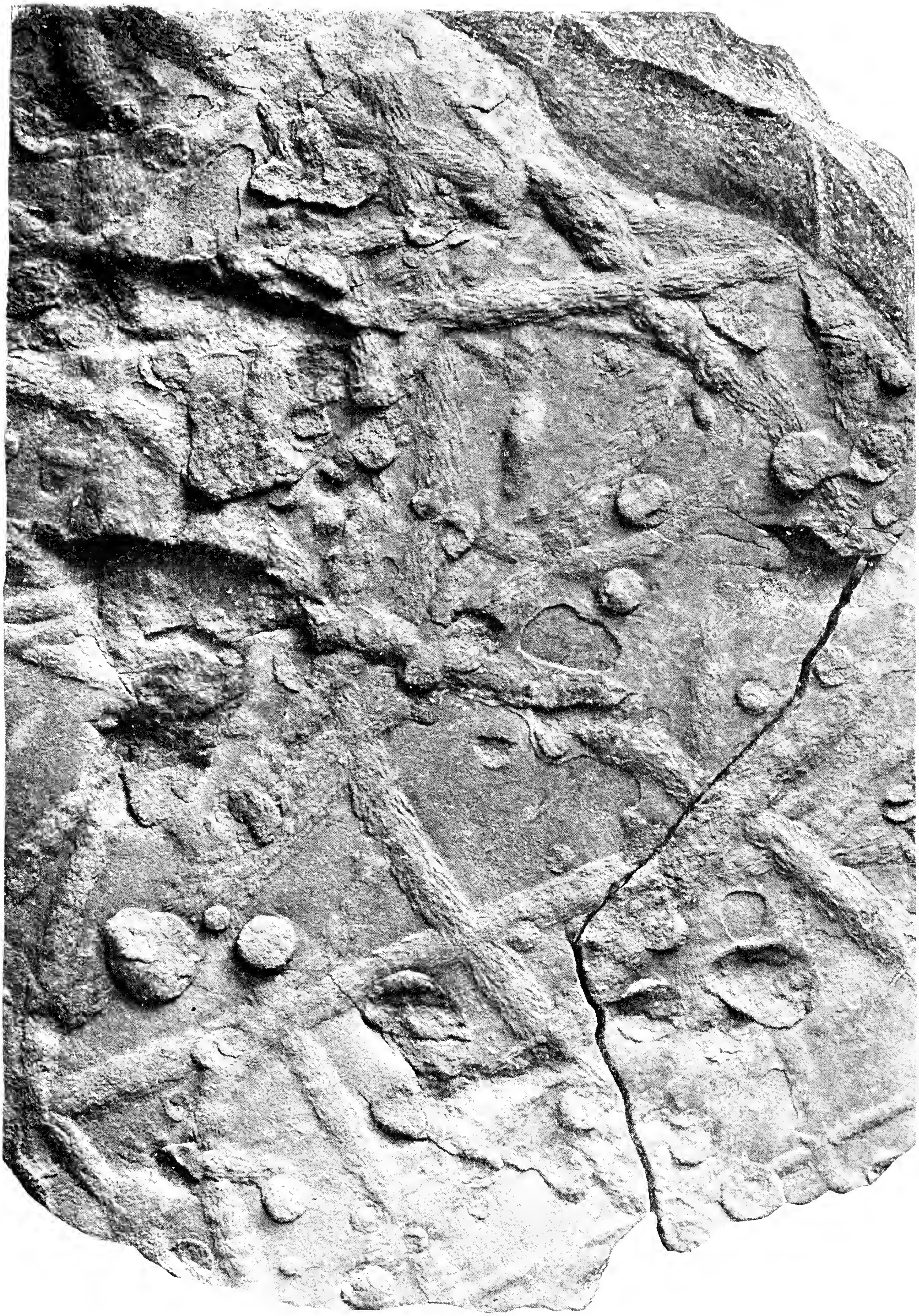
All photographs are in natural size without retouching.



Fossils from the Hermit Shale, Grand Canyon, Arizona

PLATE 5

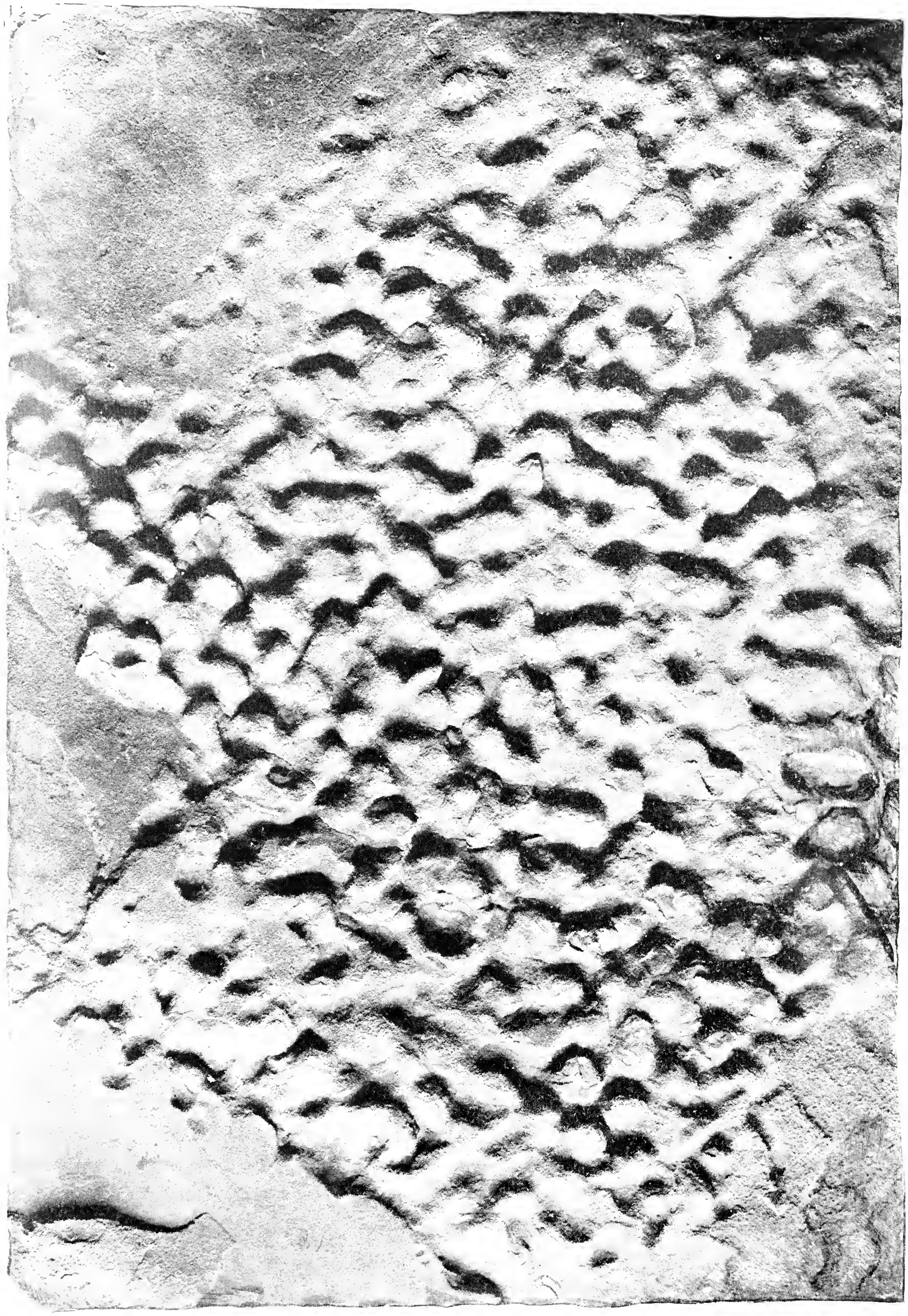
Scoyenia gracilis D. W., n. g., n. sp. Photograph, in twice natural size, of the specimen seen in Plate 4, Figure 3. In this view the plumose character of the molds is more distinctly visible; the free ends of the slender, acute, and generally appressed appendages may be seen both on the left and in the middle right of the photograph, which has not been retouched.



Fossils from the Hermit Shale, Grand Canyon, Arizona

PLATE 6

Rivularites permiensis n. sp., D. W. Portion of large slab, largely covered with the thalli of this species. The thickened protuberances, the tops of which are eroded in a part of the specimen, are inclined toward the right, presumably in the direction of the flowing water. Faint umbilication with suggestions of pores are seen at the apices of some of the protuberances. The thickened interlacing strands are seen in portions of the photograph, the points of anastomosis being located in the pits, as shown rather distinctly at the left, where, as on the upper right border also, abrasion has removed all but the pits. Photograph, unretouched, is in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

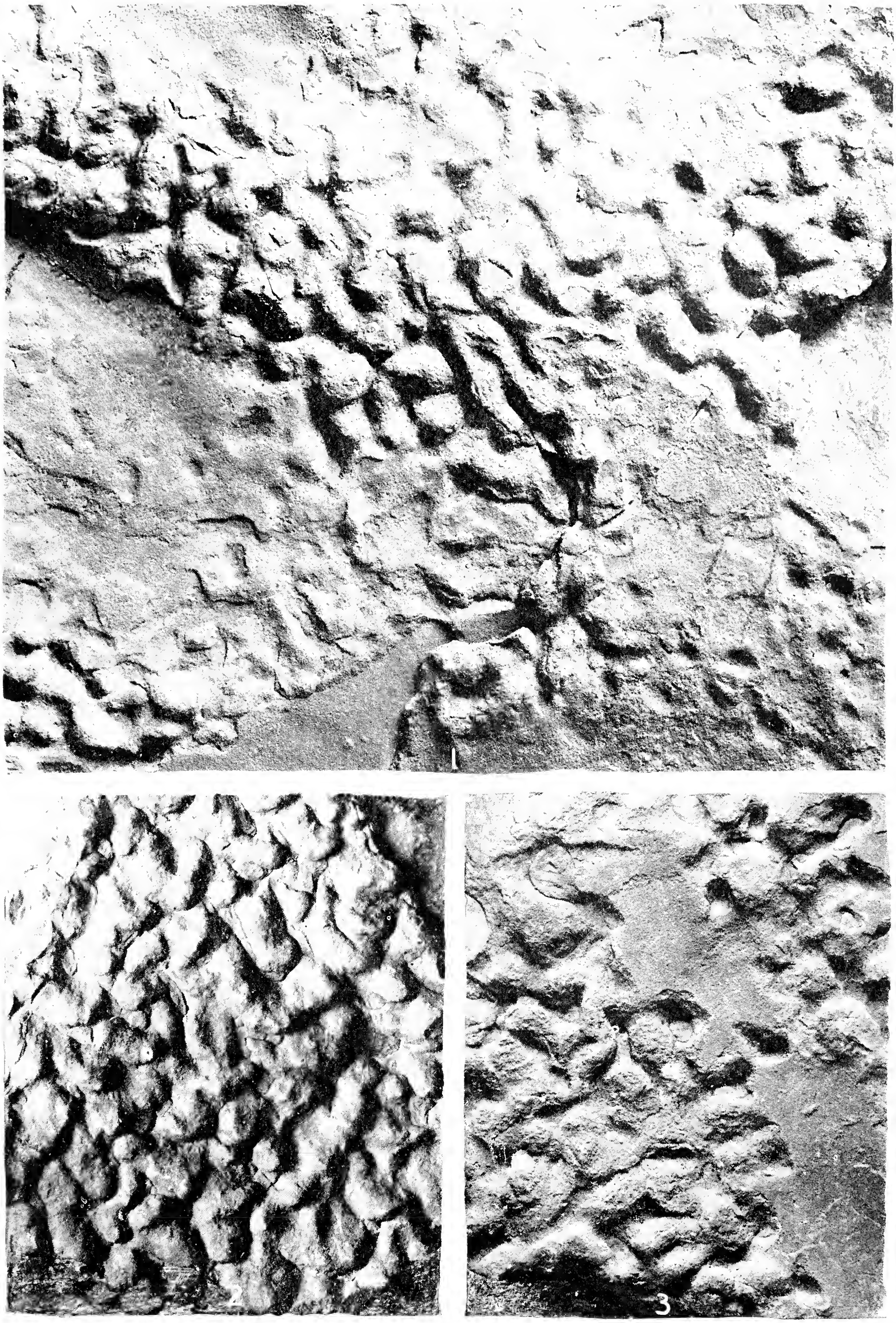
PLATE 7

FIG. 1—*Rivularites permiensis* D. W., n. sp., partially eroded. Here the thickened strands joining in the pits are more clearly shown, as also is the texture of the rock.

FIG. 2—*Rivularites permiensis* D. W., n. sp., in which the protuberances, inclined to the lower right, are but slightly eroded. Indications of a slightly velvety texture are seen in the more perfect examples. Traces of the strands are visible here and there, especially on the right.

FIG. 3—*Rivularites permiensis* D. W., n. sp., largely eroded, showing traces of the thickened strands and the pits, which appear to be the center of rhizoid holdfasts.

Specimens in natural size, unretouched.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

Plate 8

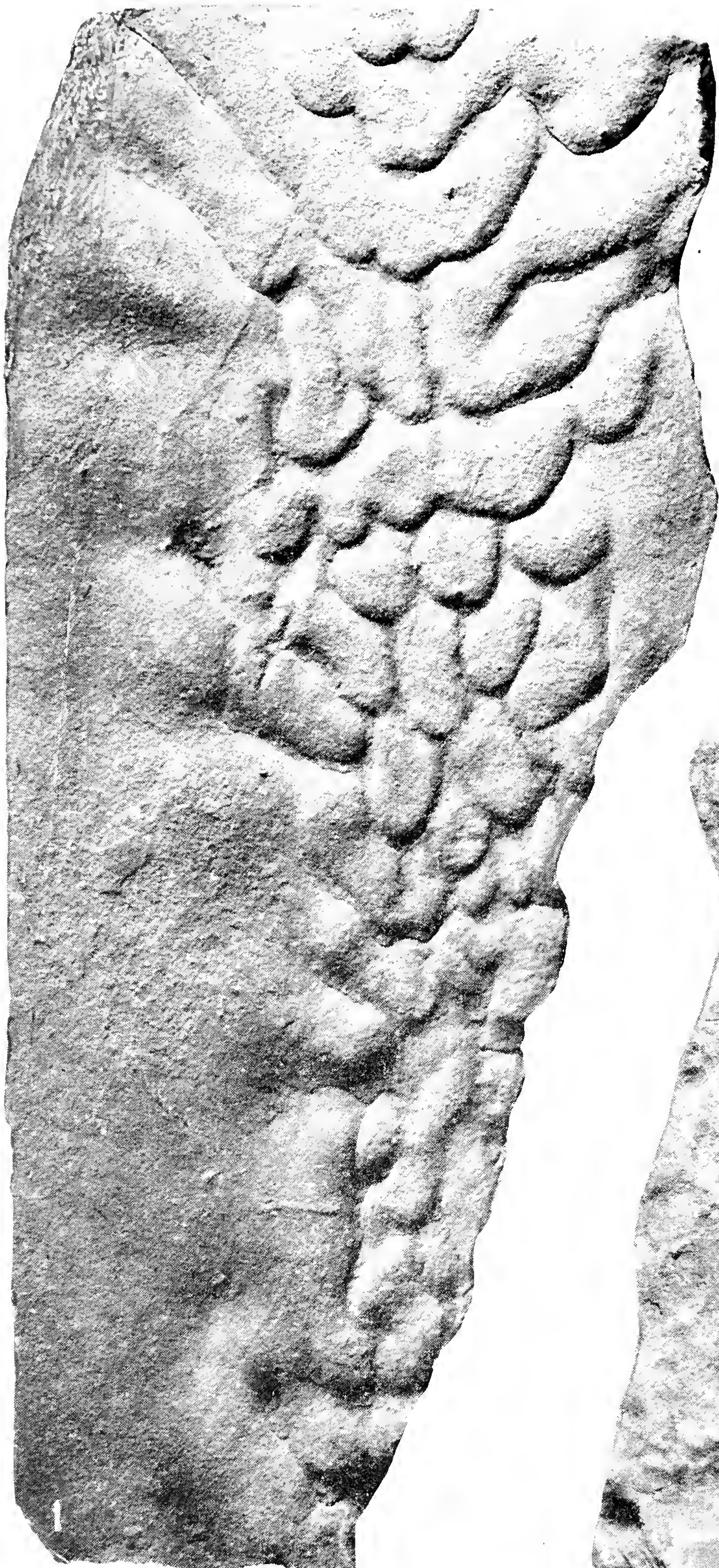
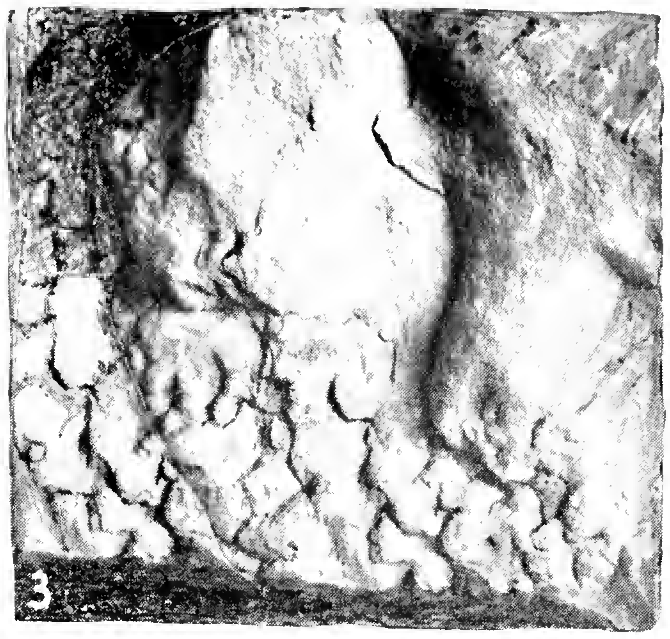
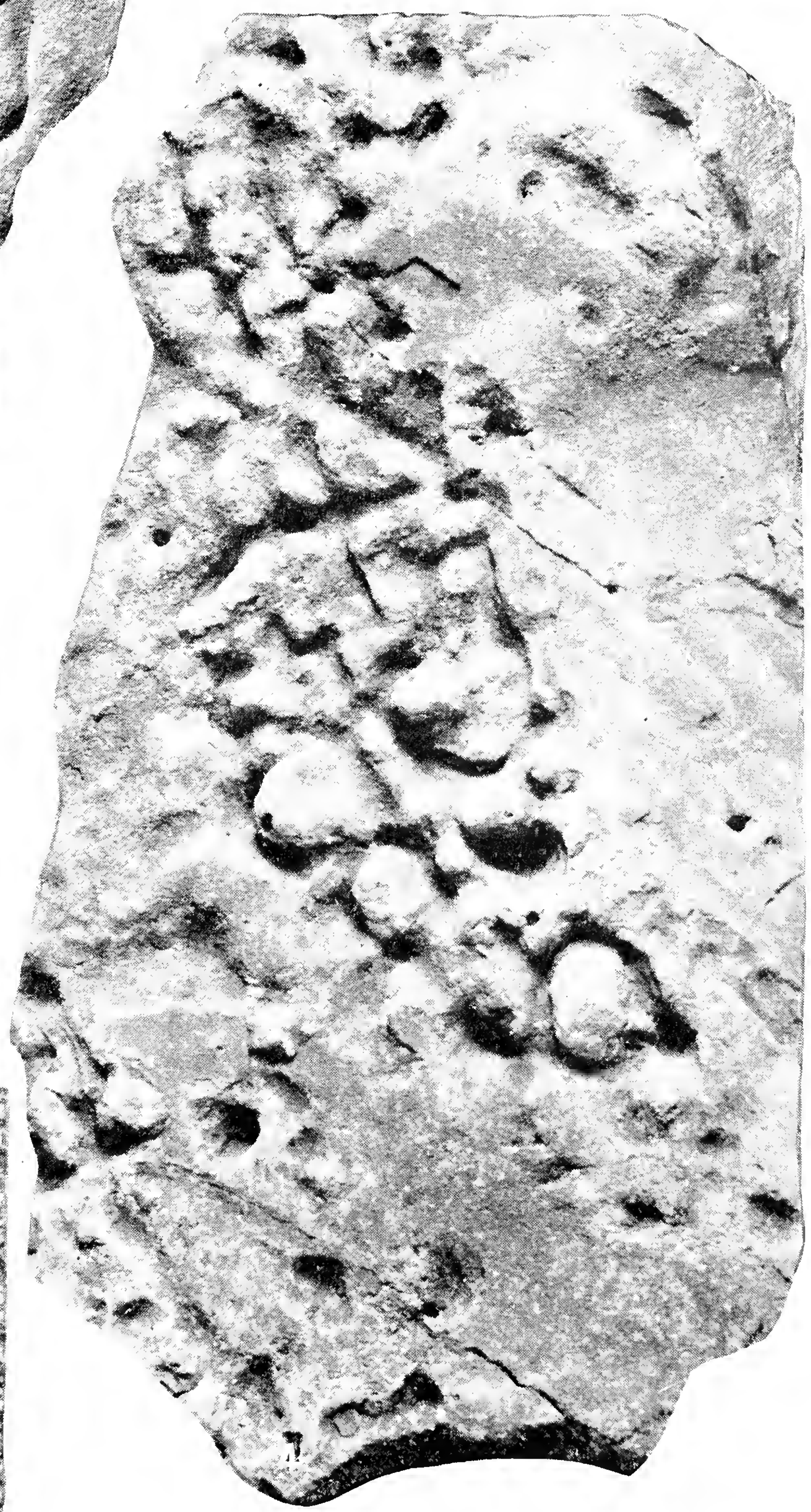
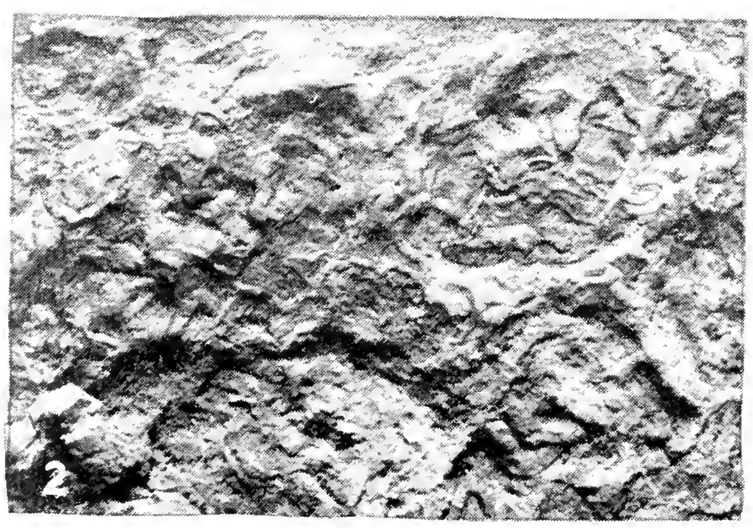
Fig. 1—*Rivularites permiensis* D. W., n. sp., narrow colony, apparently young, in which the protuberances incline downward in the photograph. Rippling at the edge is evident. Traces of circular pits left by erosion are seen on the lower left.

Fig. 2—*Rivularites permiensis* D. W., n. sp., collapsed and somewhat tangled colony in which the interlacing strands are distinct.

Fig. 3—*Rivularites permiensis* D. W., n. sp., specimen in which the mats have evidently been compressed and disturbed. The locations of the strands and pits are nevertheless clearly observable.

Fig. 4—*Rivularites permiensis* D. W., n. sp., partially abraded specimen, in which the thickened axes are seen to join in the pits in which they apparently are anchored.

All photographs in natural size.

Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 9

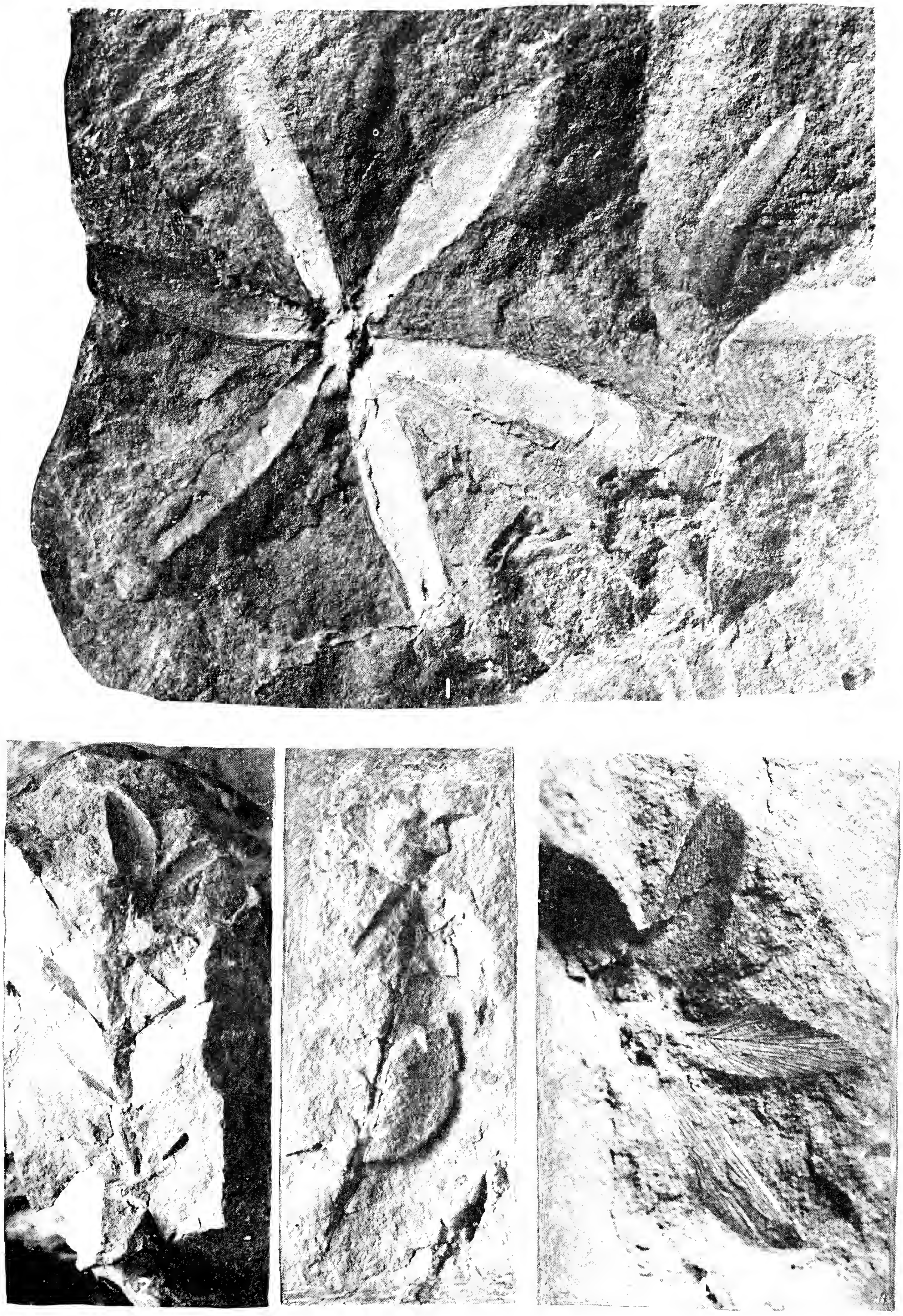
FIG. 1—*Sphenophyllum gilmorei* D. W., n. sp. Leaf verticil spreading on the bedding plane of a thin stratum of sandstone in which the stem stands erect. Specimen exhibits the characteristic aspect of the larger leaves of this species. The large size of the stem is shown by the pit collar of the verticil.

FIG. 2—*Sphenophyllum gilmorei* D. W., n. sp. Small branch standing erect in the bed which is broken at the top to expose portions of the leaves.

FIG. 3—*Sphenophyllum gilmorei* D. W., n. sp. Fragment of stem oblique to the bedding. The axis in this specimen is the most slender yet seen and the verticils are most closely placed. Its reference to this species is not without doubt.

FIG. 4—*Sphenophyllum gilmorei* D. W., n. sp. Fragment of verticil enlarged twice the natural size to show the nervation.

Figures 1, 2 and 3 natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 10

FIG. 1—*Sphenophyllum gilmorei* D. W., n. sp. Verticils of erect stems partly buried in slime on the bedding planes.

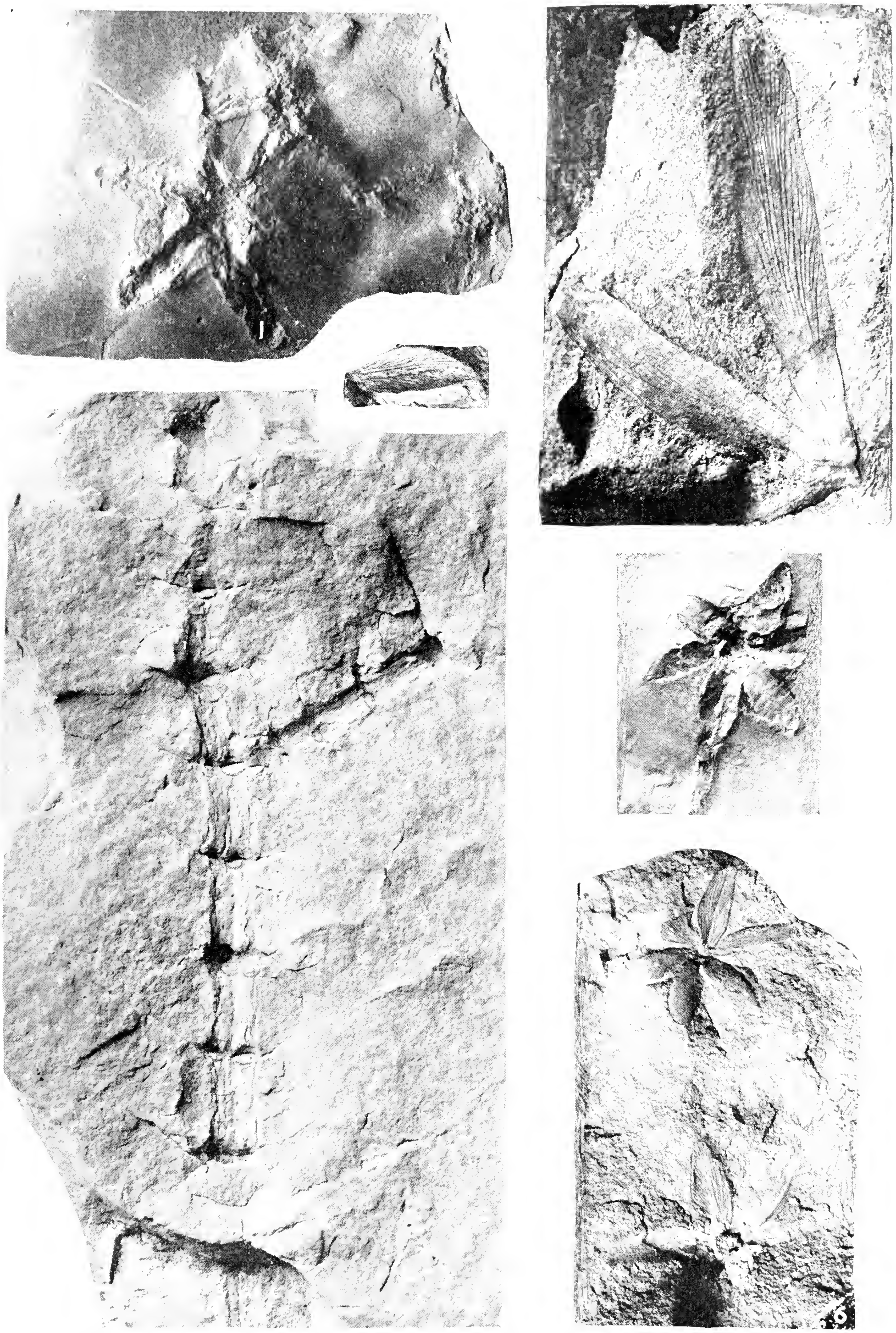
FIG. 2—*Sphenophyllum gilmorei* D. W., n. sp. Spatulate leaves showing entire or very slightly erose margin, with indication of the character of the nervation. Twice the natural size.

FIG. 3—*Sphenophyllum gilmorei* D. W., n. sp. Leaf from stem buried vertically in the sand, showing convexity and nervation.

FIG. 4—*Sphenophyllum gilmorei* D. W., n. sp. Large stem showing leaf bases of leaves buried in the matrix, with profiles of leaves broken across in splitting the rock. This stem, which is of the diameter of many of those found buried in the silty slimes, is approximately of the size of stem bearing the verticil shown in Plate 9, Figure 1.

FIG. 5—*Sphenophyllum gilmorei* D. W., n. sp. Surface of deposition in which thinly slime-covered leaves are slightly rolled backward, suggesting *Annularia* verticils. Such verticils, attached to stems erect in the silts, are frequent in the shale-filled hollow of the Hermit north of Redtop on the Hermit trail.

FIG. 6—*Sphenophyllum gilmorei* D. W., n. sp. Two verticils lying flatwise on the bedding plane. Both are attached to stems standing erect at time of burial. Two of the leaves in the upper verticil are slightly rolled like those seen in Figure 5.



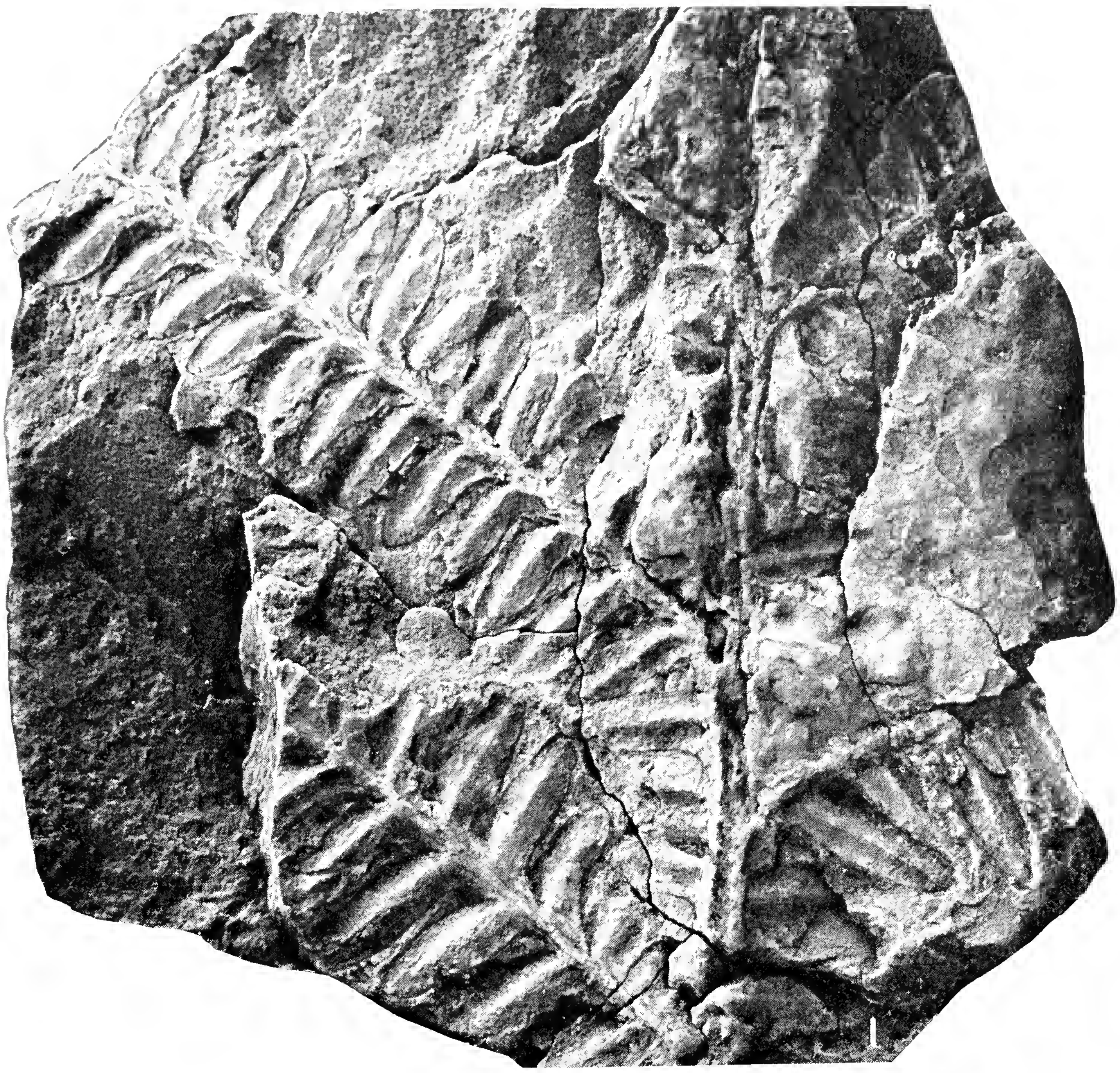
Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

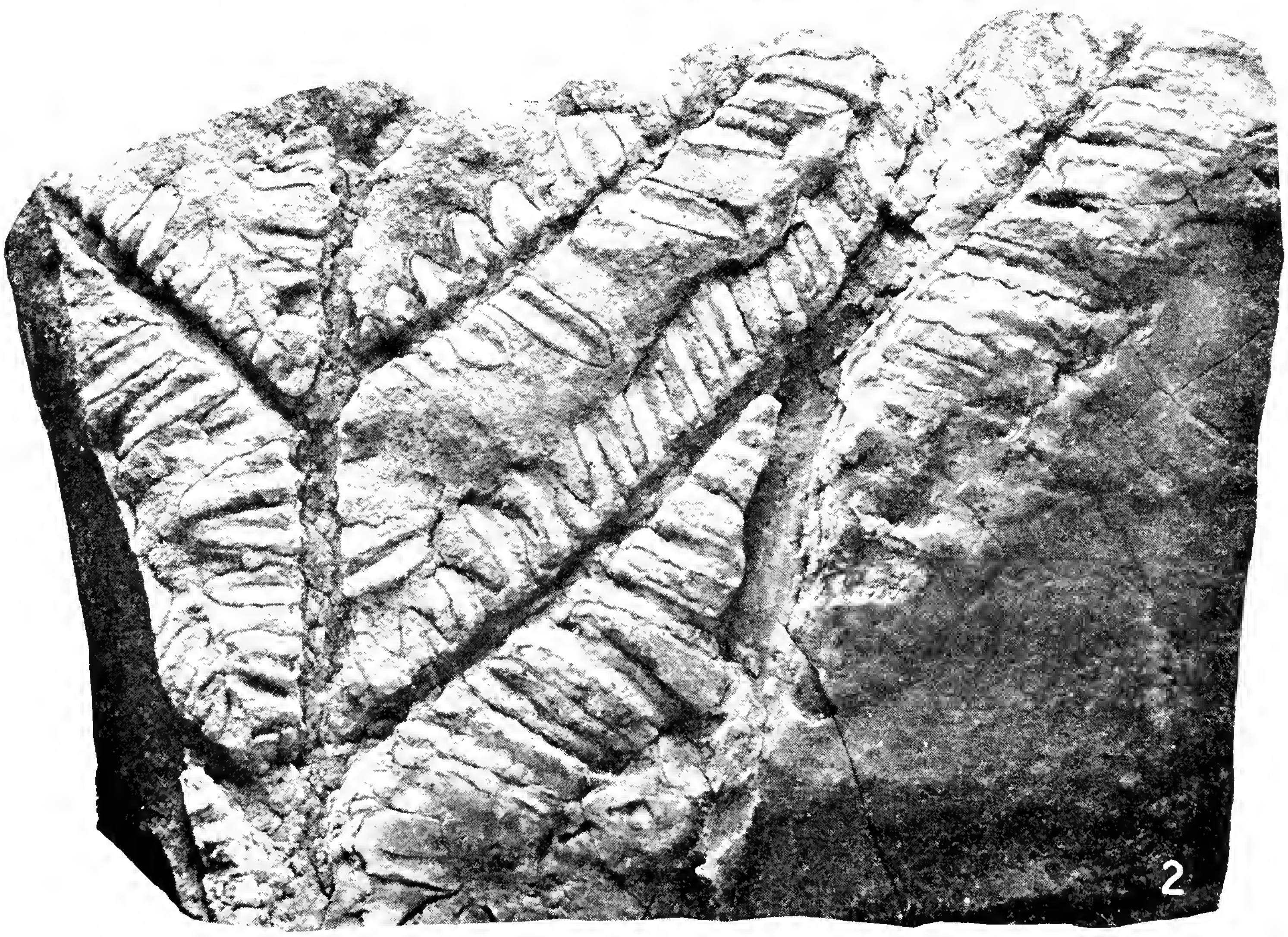
Plate 11

Fig. 1—*Callipteris conferta* (Sternberg) Brongniart. Fragment from frond, probably of moderate size, presenting pinnæ and pinnules of characters nearly typical of the species except that the nervation is concealed in the thickened leaf. It will be noted that the midribs, though in relief on the dorsal surfaces of the pinnules, are partially masked in the thick lamina, which appears to have been minutely pubescent. As in the following figure, the rachis, even in the ultimate divisions, was provided with scales, the bases of some of which may be seen in the larger of the ultimate pinnæ of the leaf.

Fig. 2—*Callipteris conferta* (Sternberg) Brongniart. In this fragment, the asymmetry of the basal portions of the ultimate pinnæ is more evident, the pinnules are marked by rounded longitudinal depressions over the midribs, and the lamina is rolled backward more or less distinctly near the border. The specimen shows imperfectly the rather densely chaffy or scaly character of the rachis even in the ultimate pinnæ.

Figures in natural size.





Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 12

FIG. 1—*Yakia* sp. ? Bipinnate fragment of frond suggestive of *Callipteris* in its structure and proportions. The pinnules are, however, marked by pits about some of which elongated appendages, possibly sporiferous or polleniferous organs comparable to those indistinctly seen in Plate 40, Figure 1, and tentatively referred to *Yakia,* are seen. The specimen, though obscure, had a very thick lamina. The condition of preservation does not reveal further details as to outlines of pinnules or nature of the fructification.

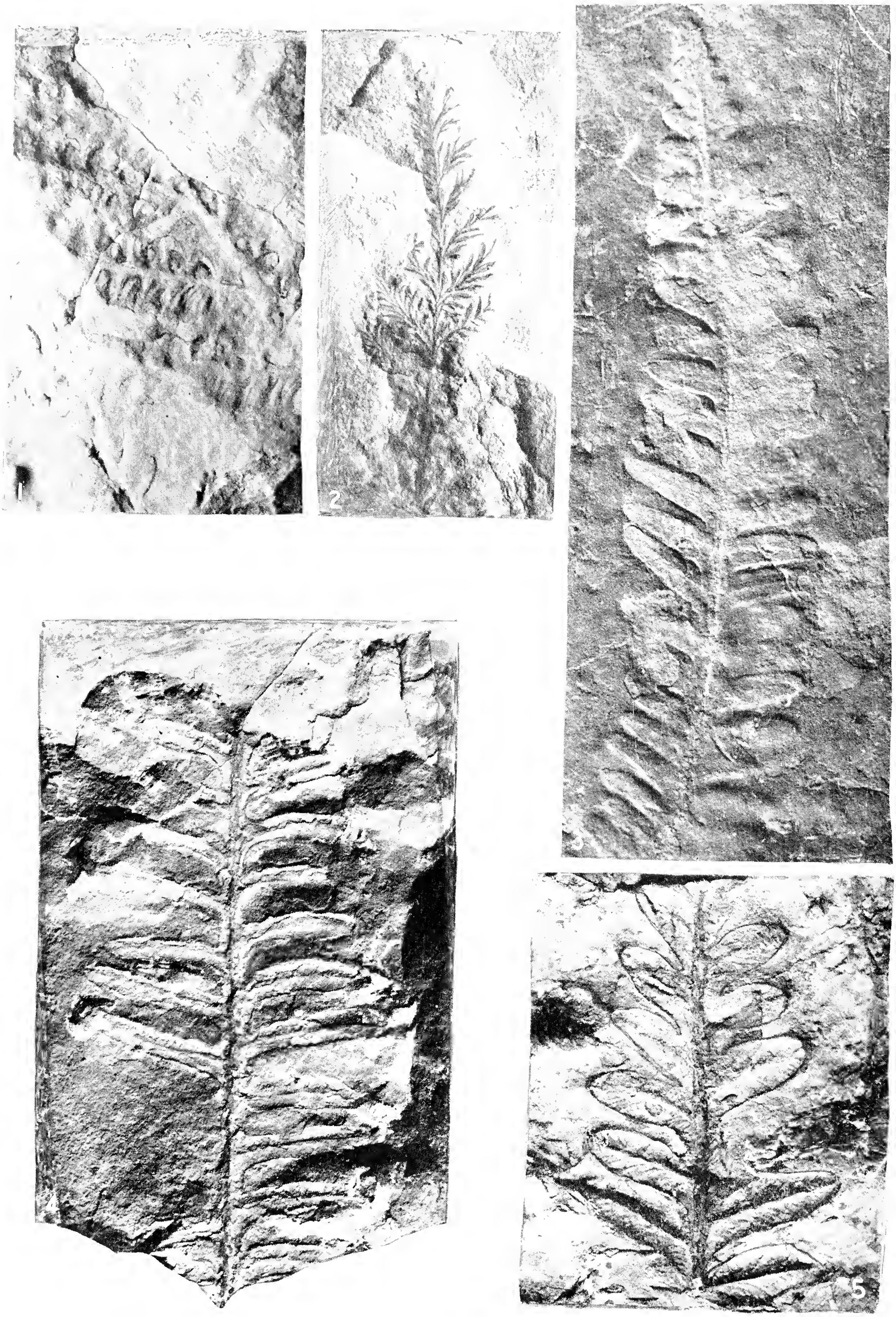
FIG. 2—*Callipteris raymondi* Zeiller. Apical portion of slender and slightly disheveled frond in which the pinnules are larger than the average in this species.

FIG. 3—*Callipteris conferta* (Sternberg) Brongniart. Pinna covered with slime before burial. This fragment is on the back of the slab showing the molds of suncracks and hailstone impressions illustrated in Plate 2.

FIG. 4—*Callipteris conferta* (Sternberg) Brongniart. Portion of ultimate pinna in which the margins of the partially slime-covered pinnules were rolled backward slightly before final deposition.

FIG. 5—*Callipteris conferta* (Sternberg) Brongniart. Fragment from relatively large pinna in which the rather coarse and relatively distant nerves are obscurely visible. The trough in the matrix along the margins of the pinna bears evidence of thickening of the lamina.

All figures in natural size.



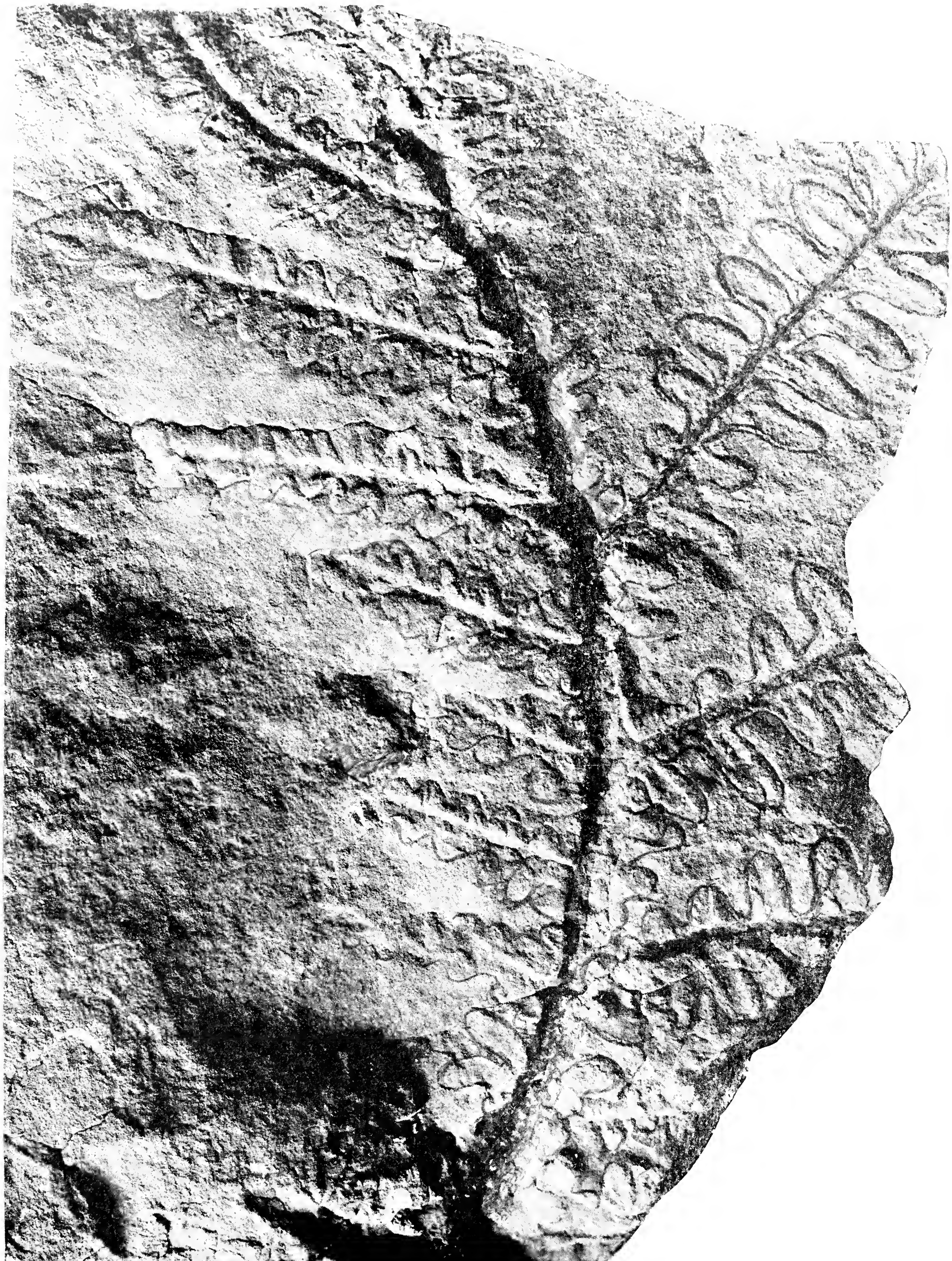
Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 13

Callipteris arizonæ D. W., n. sp. Fragment showing the greater part of a strongly asymmetrical frond which seems to have opposed another division, the extreme basal portion of whose rachis is seen at the edge of the photograph. It is, however, not clear that the specimen actually belongs to a bifurcated frond. A parent axis is imperfectly indicated in oblique fracture at the lower edge of the rock fragment.

In this example, which is Mesozoic in aspect, suggesting *Laccopteris*, the more fully developed pinna on the outer side of the frond (right in the photograph) are in strong contrast with the slender, linear, obtusely pointed pinna on the left or inner side. The specimen, by the thickening of the lamina, which was slightly turned backward at the margin, and the spongy aspect of the surface of the lamina, which is vaguely depressed over the midribs, is interpreted as xerophytic. The scabrous character of the rachis is indicated, though not well shown in the photograph.

Photograph in natural size.

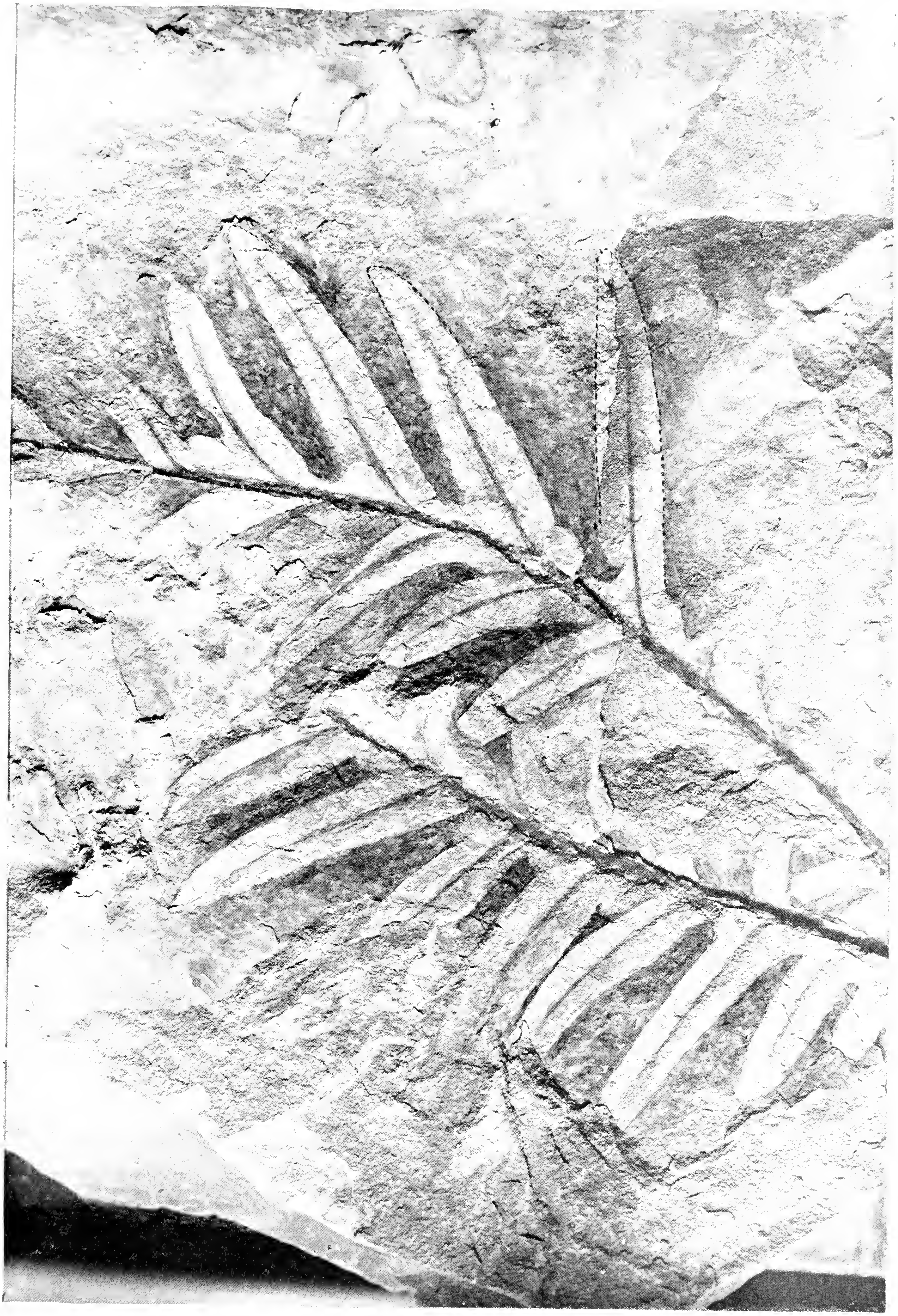


Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 14

Supaia thinnfeldioides D. W., n. sp. Though partly effaced, the specimen well illustrates the general aspect of the divisions of this characteristically dichotomous frond. The divisions are seen to lie close together, partly overlapping, and are of equal size. The greater size of the pinnules on the outer side of each division is less noticeable in this species than in some of the others of the genus. Some of the pinnules show the pouching or "ear" inflation of the lamina at the base, which in this case strongly suggests *Glenopteris sterlingi* Sell.

Photograph in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

Plate 15

Fig. 1—*Supaia thinnfeldioides* D. W., n. sp. Apical fragment of pinna in which the uppermost lobes are slightly dragged upward.

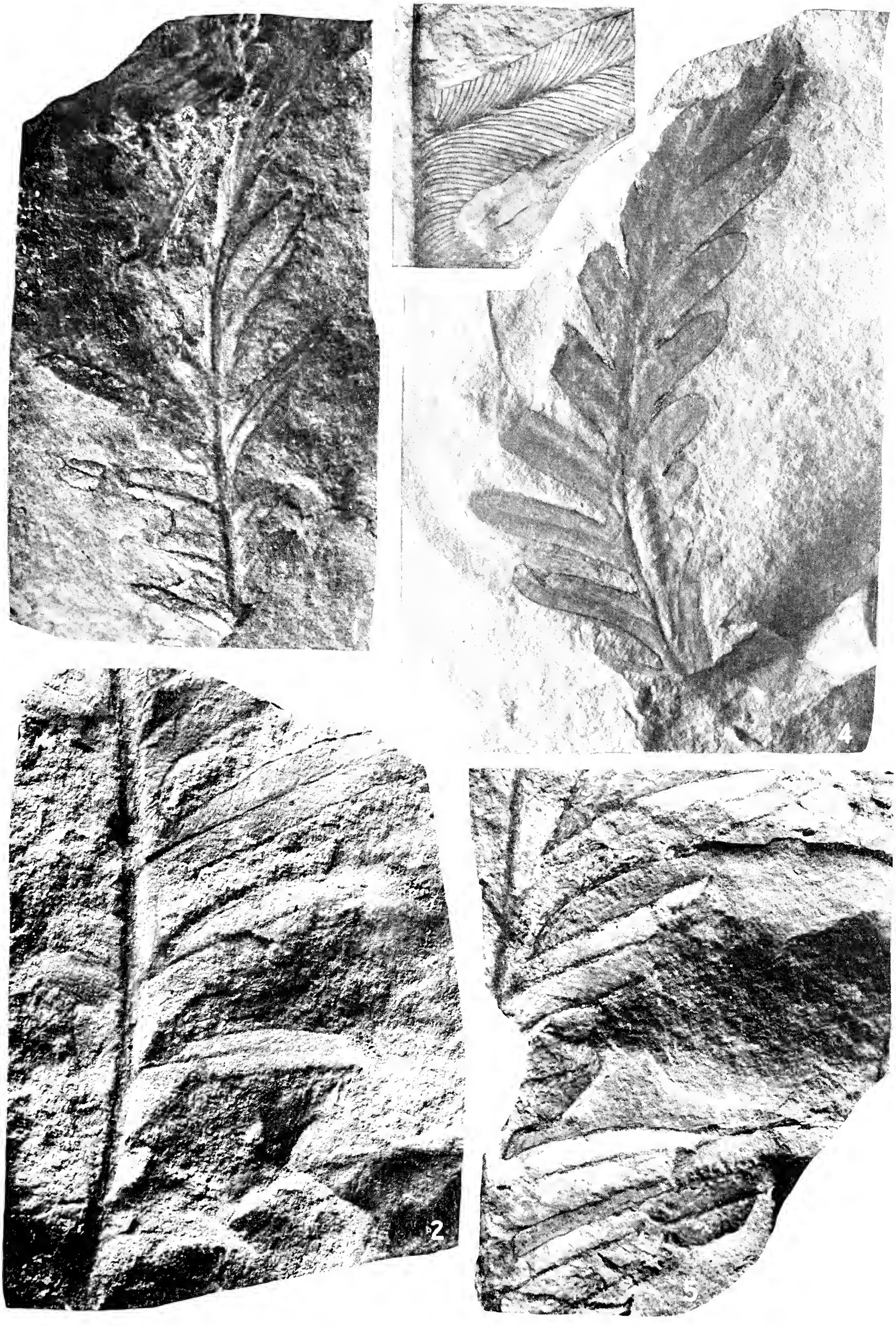
Fig. 2—*Supaia thinnfeldioides* D. W., n. sp., showing the obscure lobation of the decurrent lamina. The nervation is seen to be Alethopteroid, the nervilles being somewhat erect. The normal position of the pinnules, somewhat oblique or twisted with reference to the plane of the axis, is slightly indicated in the photograph.

Fig. 3—*Supaia thinnfeldioides* D. W., n. sp. In this small fragment, which is somewhat macerated, the nerves appear to be more regular and rather more distant than in the few portions of specimens in which any nervation whatever is visible. The reference to this species of the specimen, which differs somewhat in the features of the decurrent lamina, is slightly doubtful, notwithstanding the general similarity of the pinnules. Photograph twice the natural size.

Fig. 4—*Supaia compacta* D. W., n. sp. Apical portion of one of the divisions of the frond in which, as in most other species of this genus, the pinna is somewhat arcuate, the external pinnnules being longer than those on the inner side of the rachis.

Fig. 5—*Supaia thinnfeldioides* D. W., n. sp.

All specimens except Figure 3 in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 16

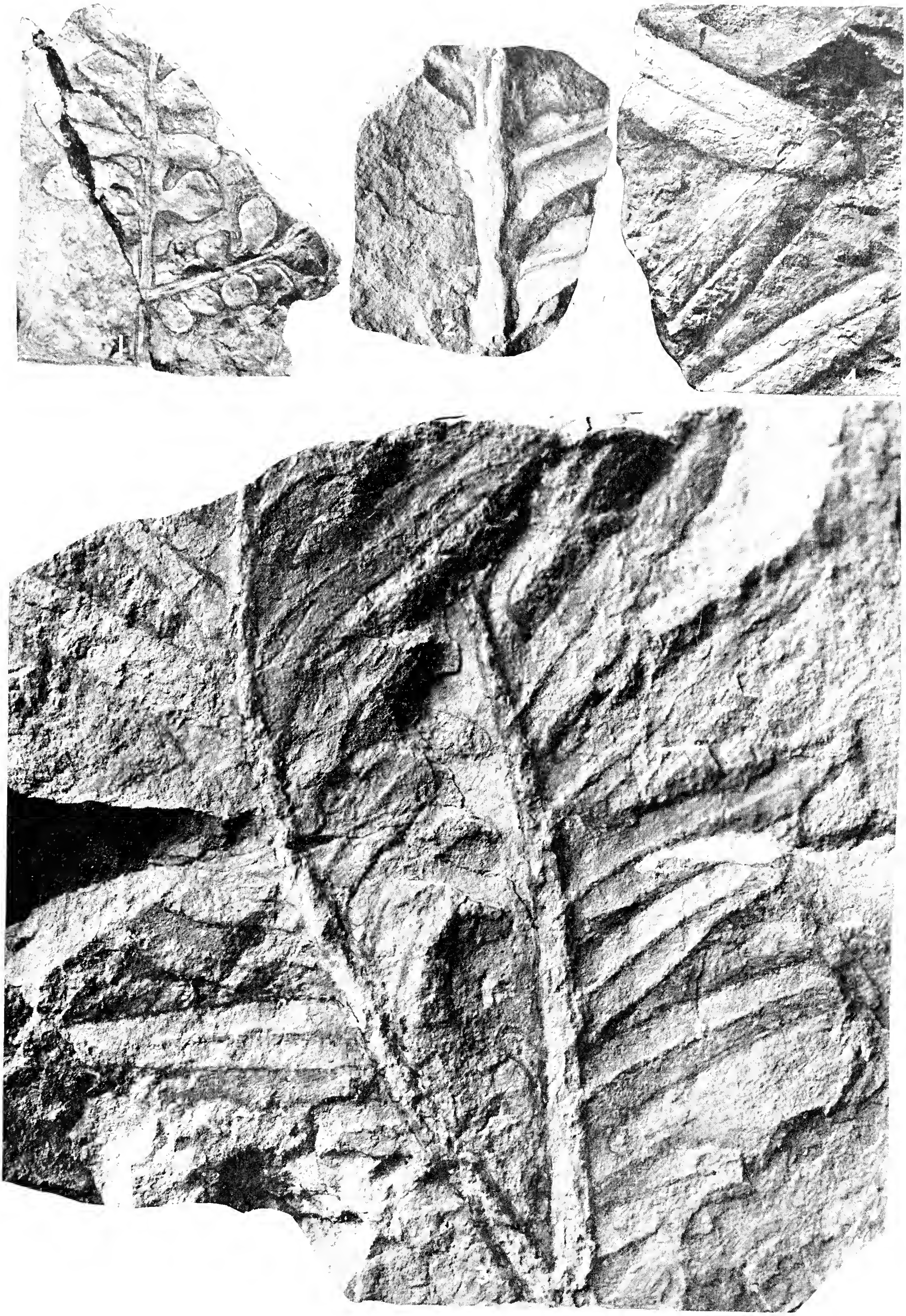
FIG. 1—*Neuropteridium ?* sp. Obscure fragment suggestive of this genus, but referred to it only with great doubt.

FIG. 2—*Supaia thinnfeldioides* D. W., n. sp. Fragment from lower portion of a relatively large pinna, which is badly macerated, with distortion of the nerves in a thick mesophyll.

FIG. 3—*Supaia thinnfeldioides* D. W., n. sp. Fragment somewhat larger than that shown in Plate 14 but exhibiting the same angle of bifurcation, overlapping of the divisions, and features of the pinnules. The scabrous character of the rachis is imperfectly shown.

FIG. 4—*Supaia compacta* D. W., n. sp. Specimen showing the greater part, including the apical portions, of four overlapping pinnules. It well illustrates the very slightly convex topography of the lamina on the ventral side, the ventrally slightly depressed midrib, which is relatively narrow and terete dorsad, and the round apex of the pinnule.

Photographs in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 17

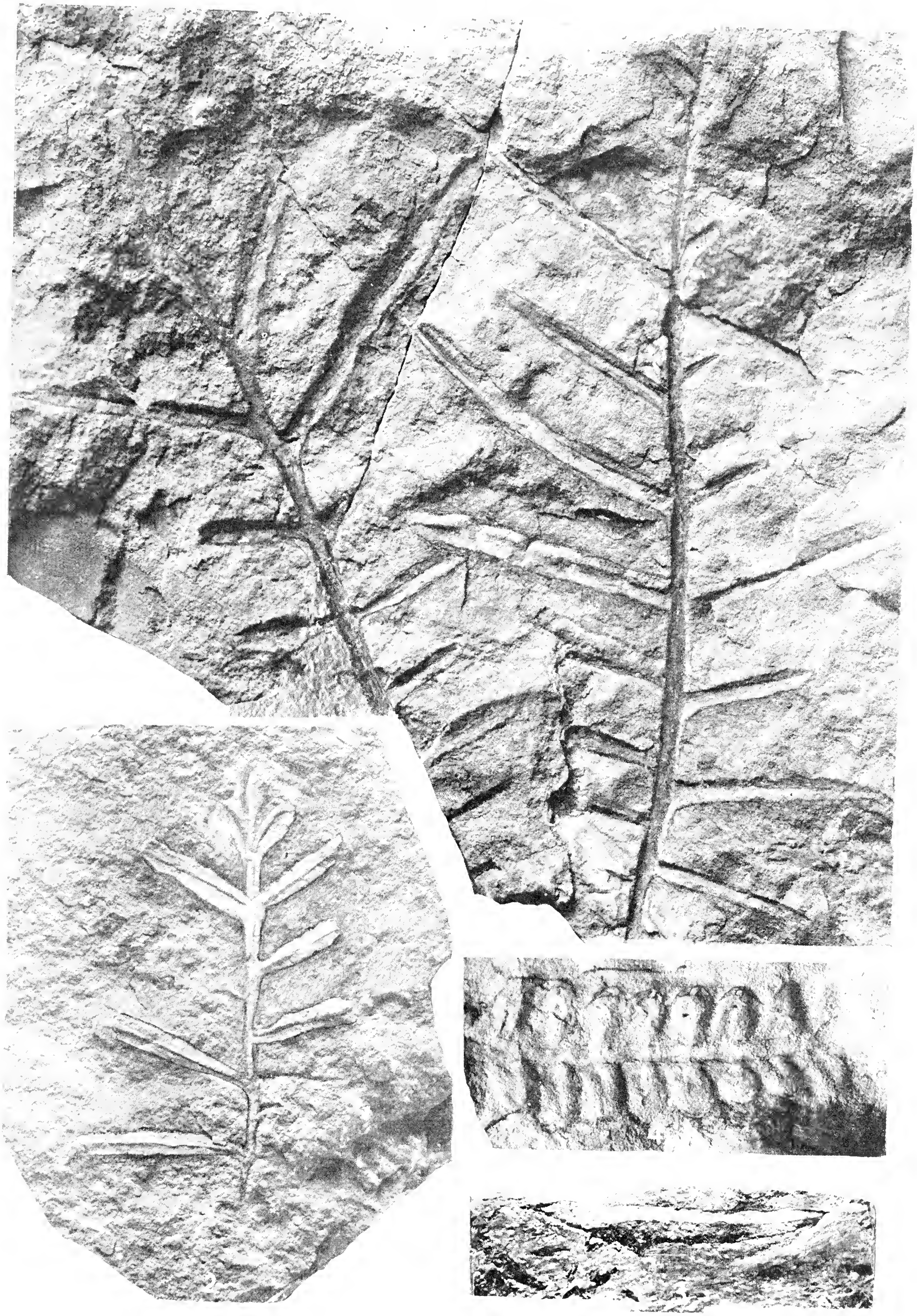
FIG. 1—*Supaia rigida* D. W., n. sp. This fragment, a portion of which was broken away from the base, shows the two divisions of the bifurcate frond in which the pinnules are very open or even slightly reflexed, very narrow, ventrally concave, slightly rounded at the edges, and narrowly decurrent. Due to the distant spacing and the rigidity of the pinnules, the narrow lamina, and the prominence of the hardly decurrent midribs, the frond has a skeletal aspect. Some of the pinnules appear slightly rolled backward, quill fashion, making them appear narrower than they really are. A striking feature, seen in several other species of the genus, is the very rapid shortening of the pinnules on the inner sides of the two divisions in passing downward.

FIG. 2—*Supaia rigida* D. W., n. sp. Apical portion of a division in which the leaves are not rolled backward.

FIG. 3—*Supaia rigida* D. W., n. sp. Portion of slender acute leaf, showing the dorsal angularity of the lamina, which in this specimen is not rolled backward at the margin. In this as in other specimens the nervation is scarcely visible.

FIG. 4—*Callipteris conferta* (Sternb.) Brongniart ? Fragment of pinna showing the greatly thickened lamina covered with a thin film of slime. The midribs, marked by depressions on the surface of the lamina, appear as the points of small rounded casts where the ends of the pinnules are eroded. Medial depressions near the bases of some of the pinnules suggest the situations of fructifications. The opposite position of some of the pinnules points to the genus *Callipteris* rather than *Pecopteris,* which in many respects the fragment strongly resembles. Photograph twice the natural size.

All photographs except Figure 4 in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 18

FIG. 1—*Supaia sturdevantii* D. W., n. sp. Fragment buried oblique to the deposit and showing the tilted or twisted positions of the pinnules, some of which are partly broken away in consequence of their obliquity. The pinnules on the right lie at an angle of about 140° to those on the left, and therefore appear more oblique in the photograph than they really are.

FIG. 2—*Supaia sturdevantii* D. W., n. sp. In this impression on the bedding plane the slightly twisted attitude of the pinnules is again shown. The pinnule is broadest three-fourths of the distance toward the apex, beyond which it contracts rapidly to a rounded slightly apiculate apex which points slightly upward—a feature not so well shown in Figure 1.

The thick pinnules in the upper part of the fragment have been mined, probably by the larvæ of some insect. They suggest the work of a Coleopterous insect.

FIG. 2-A—*Supaia sturdevantii* D. W., n. sp. Photograph, enlarged twice the natural size, to show the aspect of the leaves mined, probably by some insect larva.

FIG. 2-B—*Supaia sturdevantii* D. W., n. sp. Detail, somewhat diagrammatic, of the nervation of the pinnule seen in the lower left in Figure 2.

Figures 1 and 2 in natural size; Figures 2-A and 2-B twice natural size.

Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

Plate 19

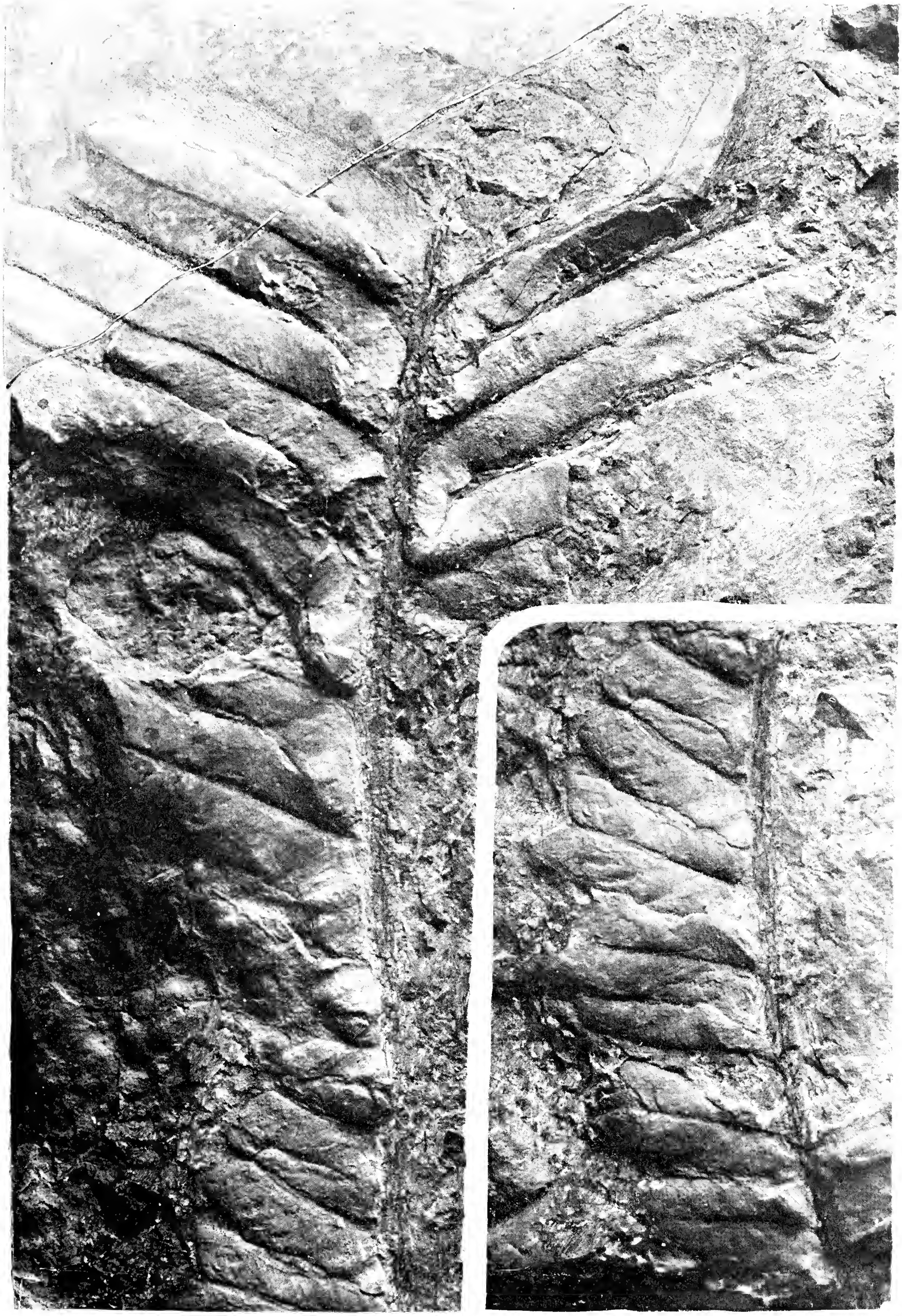
Supaia merriami D. W., n. sp. The species is characterized by the very large thick, fleshy, close-spaced pinnules, which are obtusely rounded at the apex, with ventrally slightly convex lamina and depressed broad midribs. The inset in the lower right of the plate continues the pinna downward toward the point of probable bifurcation.

In this, the most robust of the fronds of this genus yet collected in the Hermit shale, the subauriculate, puckered, bases of the pinnules are clearly shown. Plainly these pucker so as to overlap the upper margins of the preceding pinnule when compressed.

The scabrous character of the median nerve is vaguely indicated.

That the frond is probably dichotomous is rather inconclusively indicated by the arcuate form of the division, in which the external pinnules are longer than those on the inner side of the rachis. As in other species of *Supaia,* the pinna is widest near the top, below which it narrows downward to a point beneath the bifurcation of the frond.

Photograph in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 20

FIG. 1—*Supaia anomala* D. W., n. sp. Fragment from the upper part of a division showing the distant, obliquely placed, pinnules which are much narrowed on the distal side near the base. Sinuosity of the margins, more apparent in the upper portions of the large pinnules, is plainly visible. No fasciculate development of the nervation is seen to prove that the pinnule is becoming pinnatifid, as may be inferred, although no pinnatifid pinnules have been found in the collection. All the pinnules are broken and fail to show their entire length.

FIG. 2—*Supaia anomala* D. W., n. sp. Fragment from near the apex in which the pinnules are narrow and slightly more oblique. The lower pinnule on the left has a slightly sinuate margin like that seen in the pinnules of Figure 1.

FIG. 3—*Supaia anomala* D. W., n. sp. Fragment from the middle of a pinnule seen in ventral view, in which is faintly shown the oblique, slightly arched nerves which appear to fork once and may in some instances fork a second time.

Photographs in natural size.

Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 21

FIG. 1—*Supaia anomala* D. W., n. sp. Apical portion of a division showing *Megalopteris* aspect. The sinuate margin of the lower pinnule on the right accords with the larger pinnules in the middle portions of the fronds. The surface of the lamina suggests the development of nerve systems corresponding to the scallops at the margin, but such nervation is not clearly visible.

FIG. 2—*Supaia anomala* D. W., n. sp. Apical portion of another, less robust division, the upper portion of which is much abraded, on which account an unwarranted aspect of asymmetrical lobation appears. This fragment, like that shown in Figure 1, suggests *Megalopteris,* and, if isolated, might readily be regarded as representing that genus.

FIG. 3—*Supaia anomala* D. W., n. sp. Ventral view of portion of long pinnule of the species.

FIG. 4—*Supaia anomala* D. W., n. sp. Fragment of very wide pinnule showing faint sinuosity of the margin and revealing indistinct oblique nerves forking once and apparently twice in some cases.

FIG. 5—*Sphenophyllum gilmorei* D. W., n. sp. Part of fertile branch showing sporangia borne in series on the ventral side of the leaf, as in *Bowmanites*.

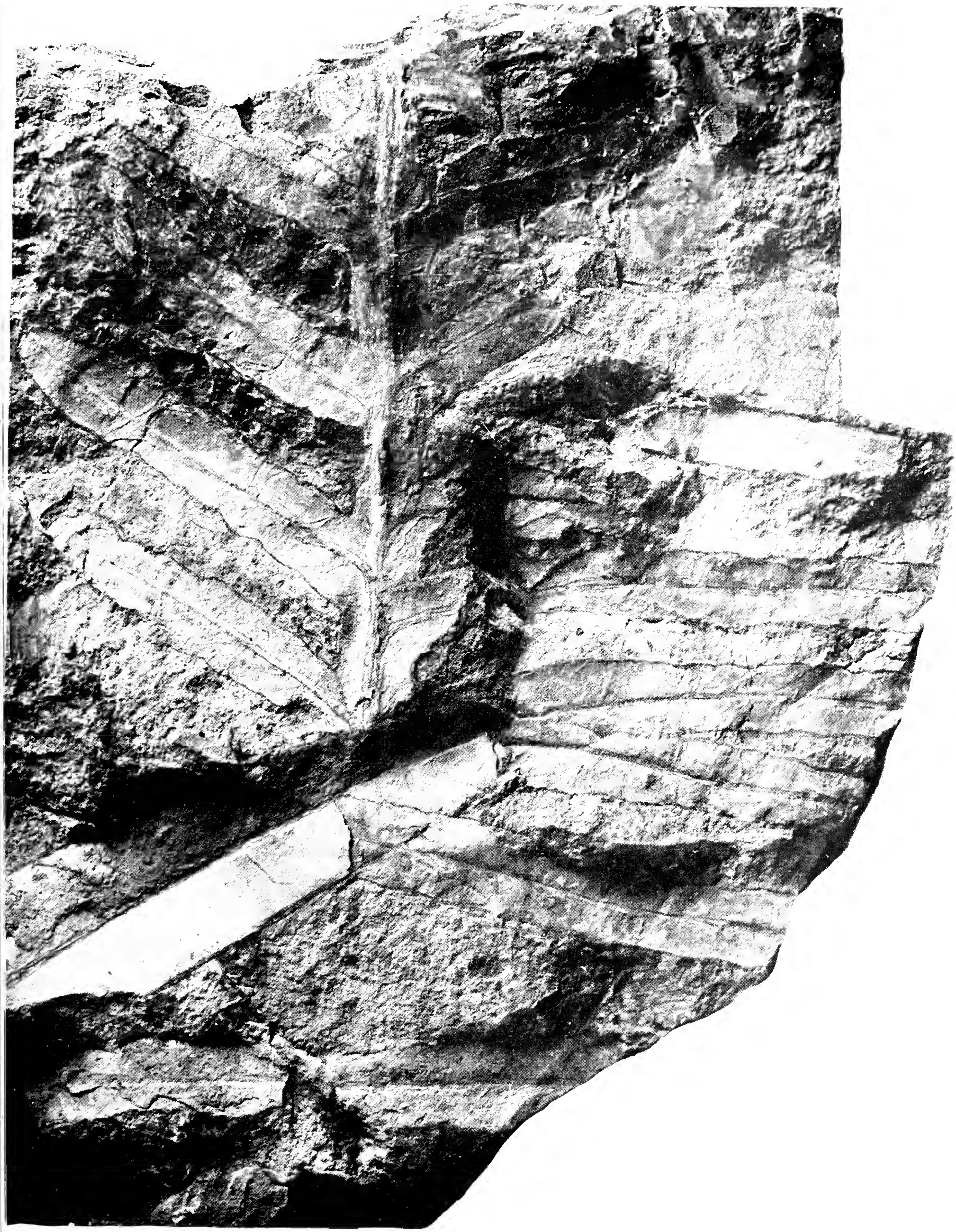
Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 22

Supaia anomala D. W., n. sp. Fragment of a division showing the characteristic decurrence of the lamina, which is sinuate at the borders. The specimen imperfectly illustrates the enormously elongated outer pinnules which, like the inner, have sinuate borders.

A fragment of *Tæniopteris angelica* D. W., n. sp., is obliquely buried in the lower part of the slab.

Photograph in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 23

FIG. 1—*Supaia linearifolia* D. W., n. sp. Fragment from the middle portion of a frond in which, in the center, is seen the left hand division, with extremely long pinnules, the bases of none of which are lobate, while the pinnules on the inner side of the rachis are very rapidly narrowing to the point of bifurcation. It is probable that the outer pinnules also narrow with anomalous rapidity toward the base of the limb, though they are longer throughout the frond than the inner pinnules.

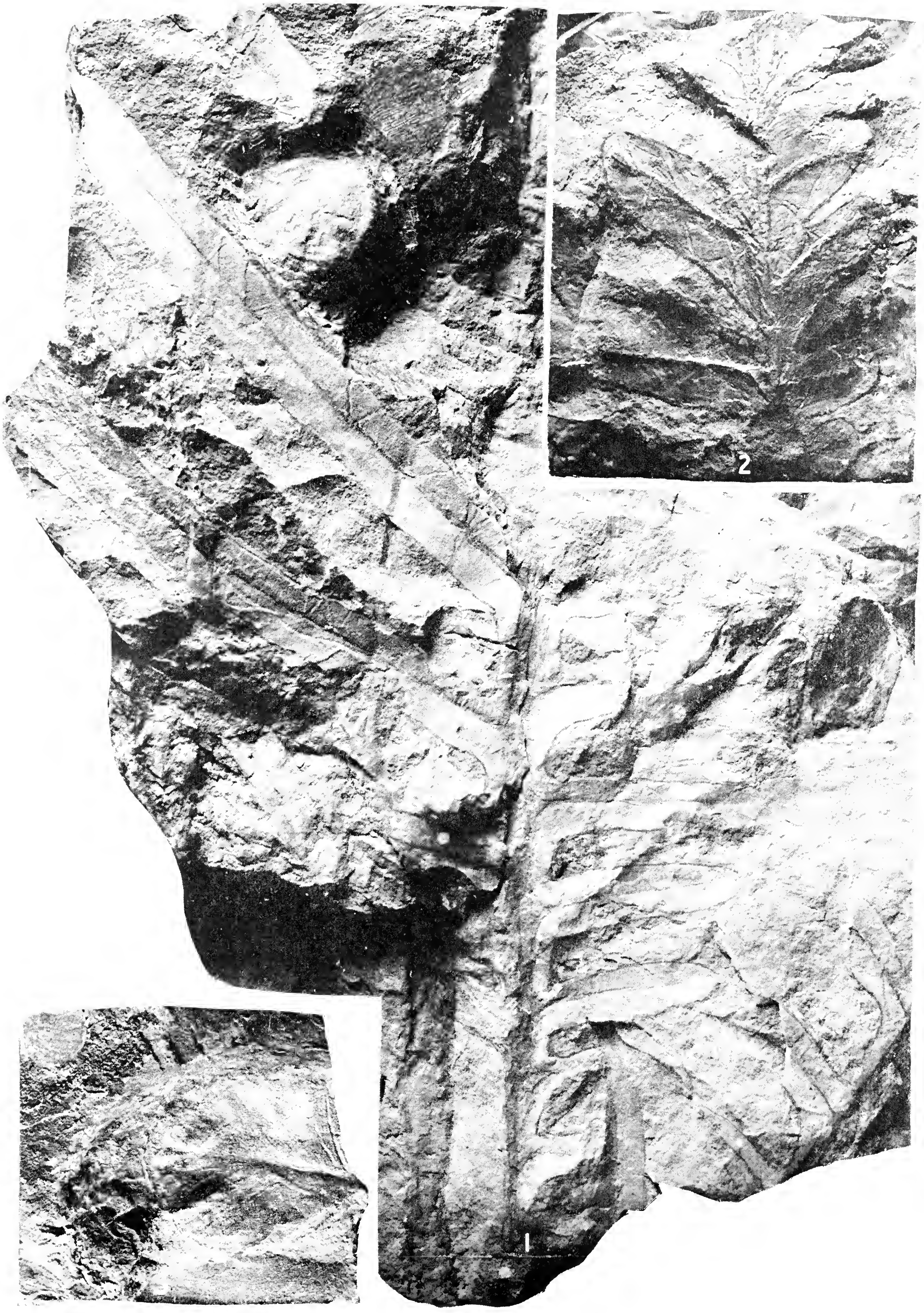
A portion of the right division of the same frond lies across the corner of the slab. This indicates that the two divisions overlap little, though the outspread is relatively extraordinary.

A fructification, in size and form agreeing with those later described as *Eltovaria*, but lacking surface details, is partly uncovered in the upper part of the specimen.

FIG. 2—*Brongniartites ? aliena* D. W., n. sp. Upper portion of a division of a very young frond, the reference of which to the above named species is not beyond doubt. It will be noted that the lobes or pinnules are hardly narrowed on the lower decurrent side, though notched on the distal side of the base, while the midribs are strongly in dorsal relief and extend, while tapering, nearly to the apices of the pinnules.

FIG. 3—*Brongniartites ? yakiensis* D. W., n. sp. Apical portion of one of the larger leaves, in which the nervation is faintly indicated.

All photographs in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 24

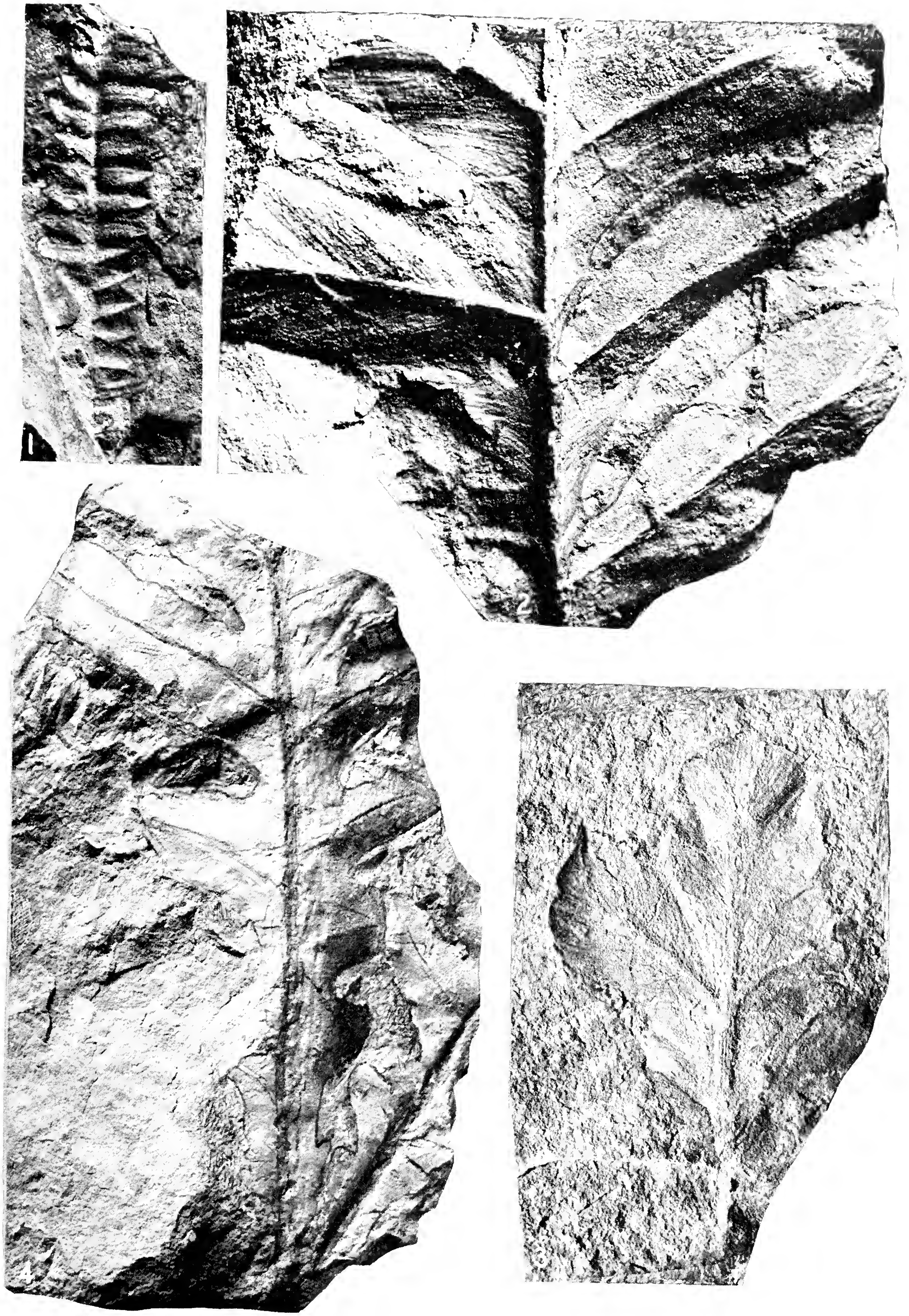
FIG. 1—*Supaia ?* sp. Small fragment referred with great doubt to this genus. A notable feature is the depressed axis of the lobe, originating nearly at right angles to the rachis and passing nearly straight to the apex, which is thick and possibly rolled backward.

This specimen was at first tentatively placed under *Gigantopteris*.

FIG. 2—*Brongniartites ? yakiensis* D. W., n. sp. Twice the natural size. Portion from the middle of a pinna of this species showing the lamina, widely decurrent in the upper part and becoming dissected nearly to the midrib in the proximal portion, the strong midribs being hardly decurrent and carinately prominent dorsally. The nervation is shown unusually well in this fragment, which belongs to the left of the two divisions, as is indicated by the longer pinnules on that side and the curve of the rachis near the base of the fragment.

FIG. 3—*Brongniartites ? yakiensis* D. W., n. sp. Apex of a division in this species, seen in dorsal view. The fragment, in which the nervation is imperfectly visible, appears slightly crenulate or sublobed, possibly as the result of conditions of preservation. The much stronger midrib and longer lobe on the left mark that side as external with reference to the two divisions.

FIG. 4—*Supaia anomala* D. W., n. sp. Lower portion of frond, including point of bifurcation, showing the reduction of the pinnules on the inner sides of the divisions. The reference of this specimen to *Supaia anomala,* in the absence of requisite details as to nervation, is based upon the resemblance of the basal portions of the outer pinnules at the top of the fragment to the pinnules in the upper part of the frond of this species.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 25

Supaia subgoepperti D. W., n. sp. The fragment shows, at the left, portions of the largest leaves found, while on the right the two fragments, less fully developed, appear to represent a younger stage. Though the actual junction of the two pinnæ on the right in the photograph is not clearly demonstrated, the trend of the rachis and the pitting in the rock indicate almost beyond question that both are the divisions of a single frond.

Photograph in natural size.

Fossil Plant from the Hermit Shale, Grand Canyon, Arizona

PLATE 26

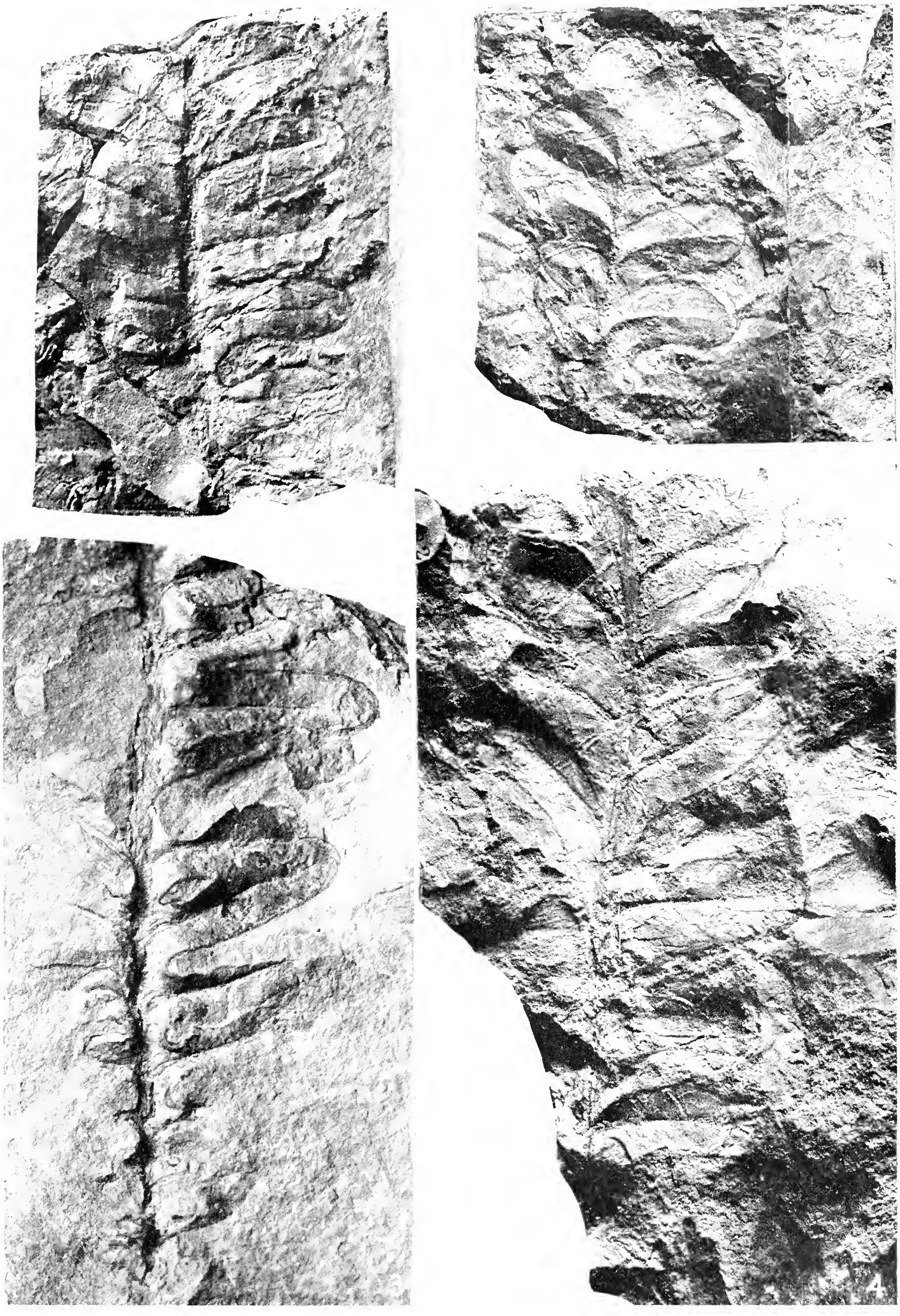
FIG. 1—*Brongniartites ? aliena* D. W., n. sp. Fragment from lower part of left hand pinna.

FIG. 2—*Brongniartites ? aliena* D. W., n. sp. One side of very young plant. Note the reduction, in passing downward, of the pinnules on the inner (left) side of the pinna.

FIG. 3—*Supaia compacta* D. W. n. sp. Lower part of pinna showing the ventrad protuberance of the lamina between the pinnules.

FIG. 4—*Brongniartites ? aliena* D. W., n. sp. Fragment from the upper part of a pinna. The bases of the pinnules are relatively broader, especially on the distal side, than in *Supaia*, and the thick midribs taper rapidly.

Figures in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

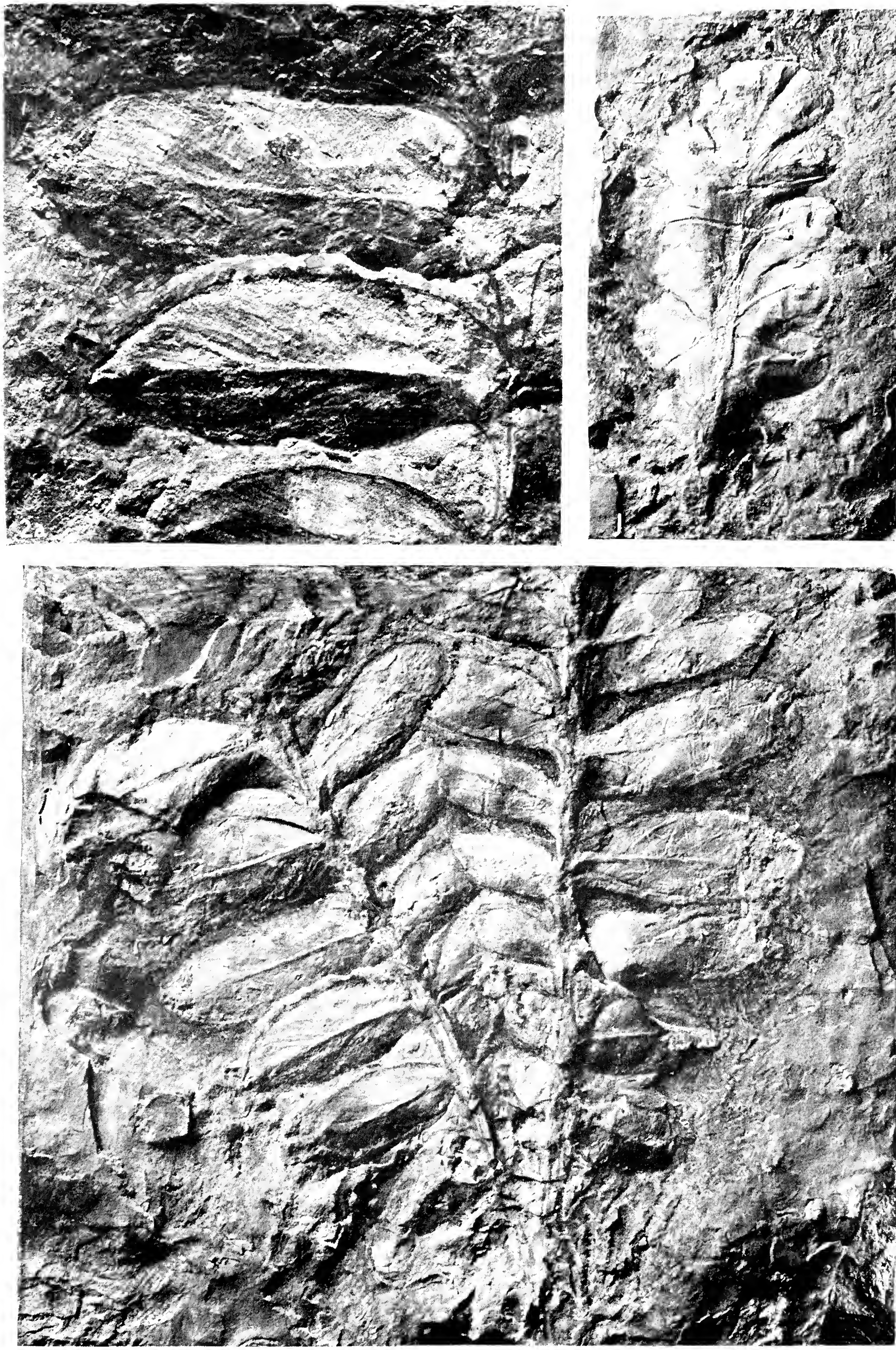
PLATE 27

FIG. 1—*Brongniartites ? aliena* D. W., n. sp. Upper part of young pinna a short distance above the bifurcation.

FIG. 2—*Brongniartites ? aliena* D. W., n. sp. Middle portion of mature bipartite frond showing the relations of the divisions, the upper portions of which are wanting. Traces of the reduced or rudimentary pinnules on the main axis just below the point of bifurcation are shown in the photograph.

FIG. 2A—*Brongniartites ? aliena* D. W., n. sp. Lower pinnules on the left of the same specimen photographed twice the natural size to show the nervation.

Figures 1 and 2 in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

Plate 28

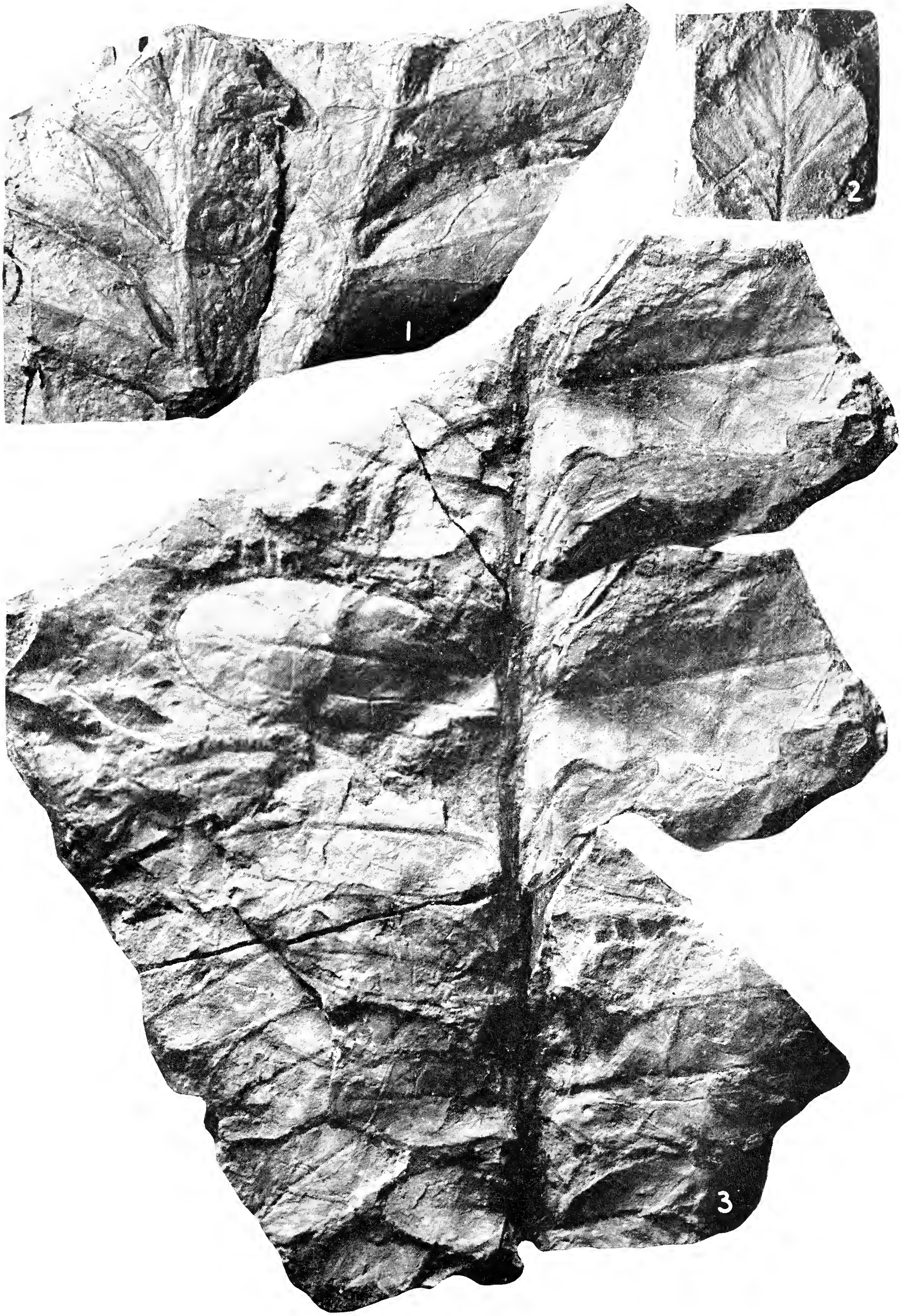
Fig. 1—*Brongniartites? yakiensis* D. W., n. sp. Portion of the middle part of a young frond of this species. In this dorsal view the lamina of the pinnules is seen to be strongly convex.

The impression of a seed about 12 mm. in length and 9 mm. in width is seen in contact with the rachis of the left-hand pinna a little to the left of the center of the photograph. In the impression the seed is placed as though attached to the rachis.

Fig. 2—Apex of pinna of *Brongniartites? yakiensis* D. W., n. sp.

Fig. 3—*Brongniartites? yakiensis* D. W., n. sp. Portion of large frond of the species in ventral view. The largest pinnules are incomplete but the form of the typical pinnule of smaller size is shown near the center of the fragment. The rachis of the twin pinna is seen at the margin on the left of the photograph and its pinnules are overlapped by the inner pinnules of the pinna on the right. The fracture at the lower edge of the specimen is about 3½ centimeters above the bifurcation of the frond.

All photographs in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 29

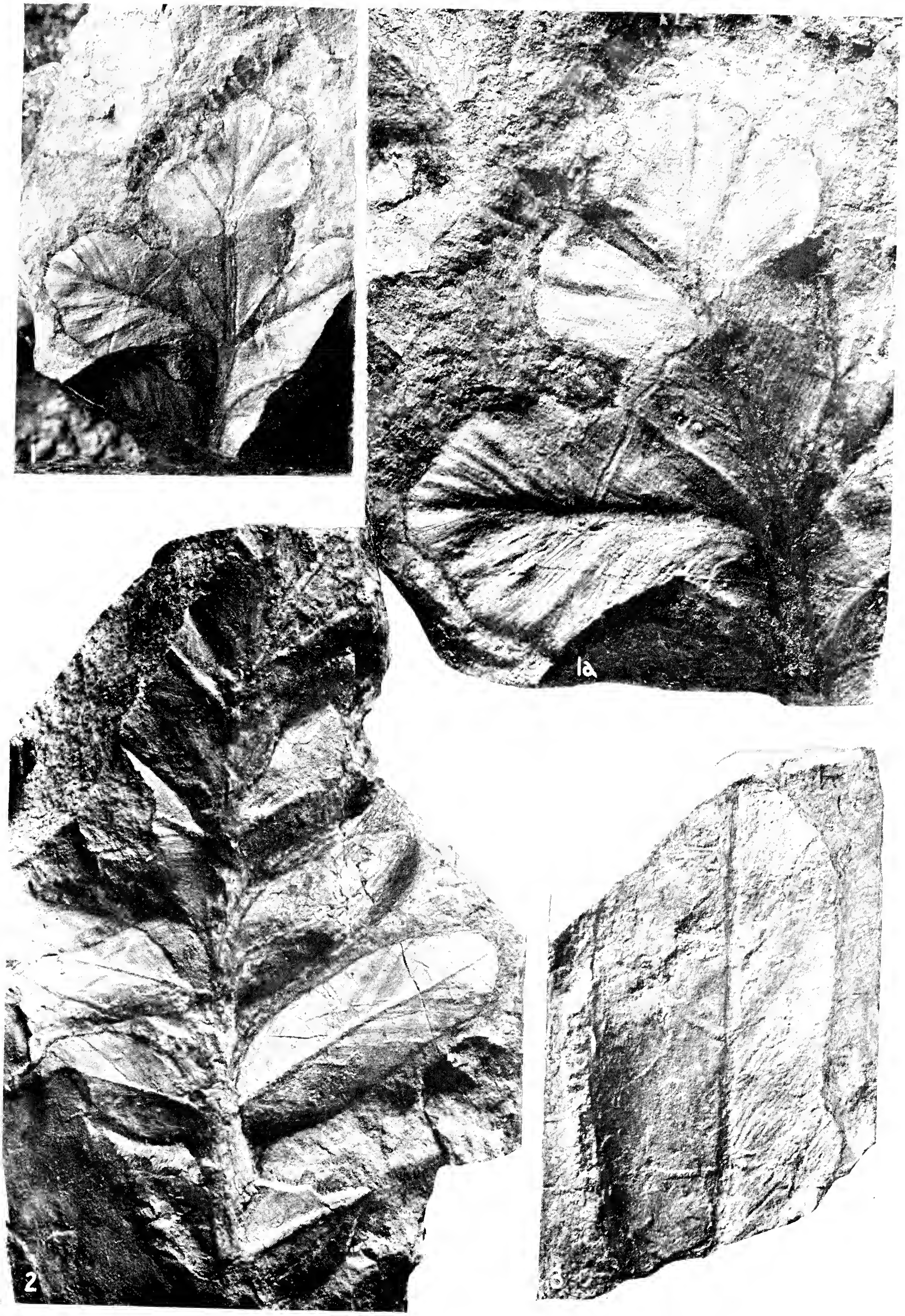
FIG. 1—*Brongniartites ? yakiensis* D. W., n. sp. Top of pinna showing apex and two young connate leaves.

FIG. 1A—*Brongniartites ? yakiensis* D. W., n. sp. Same specimen enlarged twice the natural size to show the nervation and slightly crenulate border near which the lamina is ventrally convex.

FIG. 2—*Brongniartites ? yakiensis* D. W., n. sp. Upper part of young pinna showing the convexity of the pinnules as viewed from beneath and the trough formed by the decurrent lamina, which is here, in dorsal view, seen to be raised toward the axis.

FIG. 3—*Brongniartites ? yakiensis* D. W., n. sp. View of leaf, enlarged twice the natural size, to show the slightly irregular border and the aspect of the nervation.

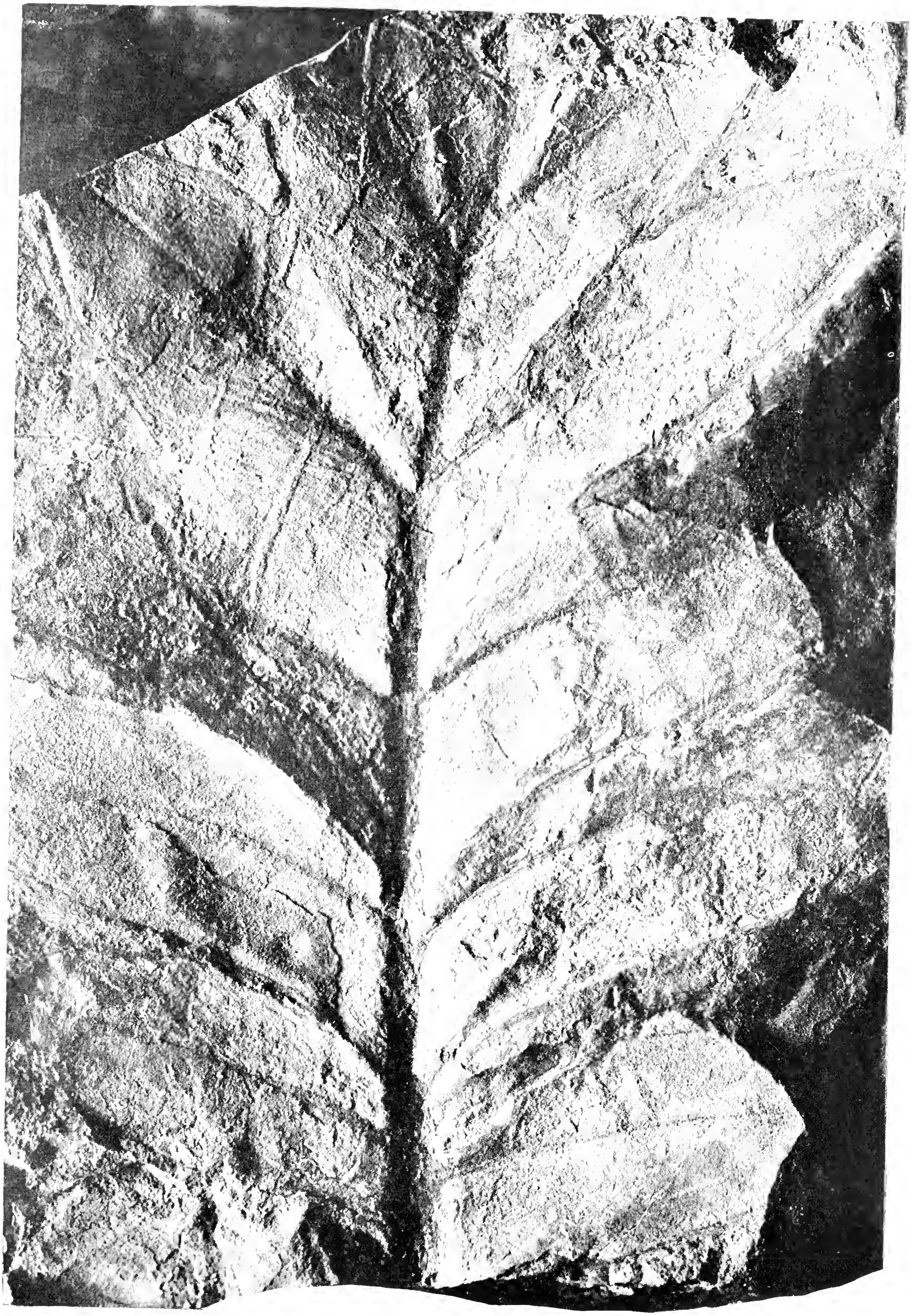
Figures 1 and 2 in natural size; Figures 1A and 3 twice natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

Plate 30

Brongniartites ? yakiensis D. W., n. sp. In this photograph, twice the natural size, the leathery texture of the frond is indicated. The creases betwen the pinnules in the upper part are due to the sloping of the lamina downward toward the midrib and rachis on the ventral side. The nervation is faintly indicated in portions of the specimen. Also at several points are seen impressions or molds made by the yarn-like appendages which appear to originate in the axils of the median nerves. The appendage on the left middle of the photograph winds diagonally across the succeeding pinnule. Another is seen crossing the lower edge of next to the lowest pinnule on the left. The impression of a third is vaguely shown on next to the lower pinnule on the right.



Fossil Plant from the Hermit Shale, Grand Canyon, Arizona

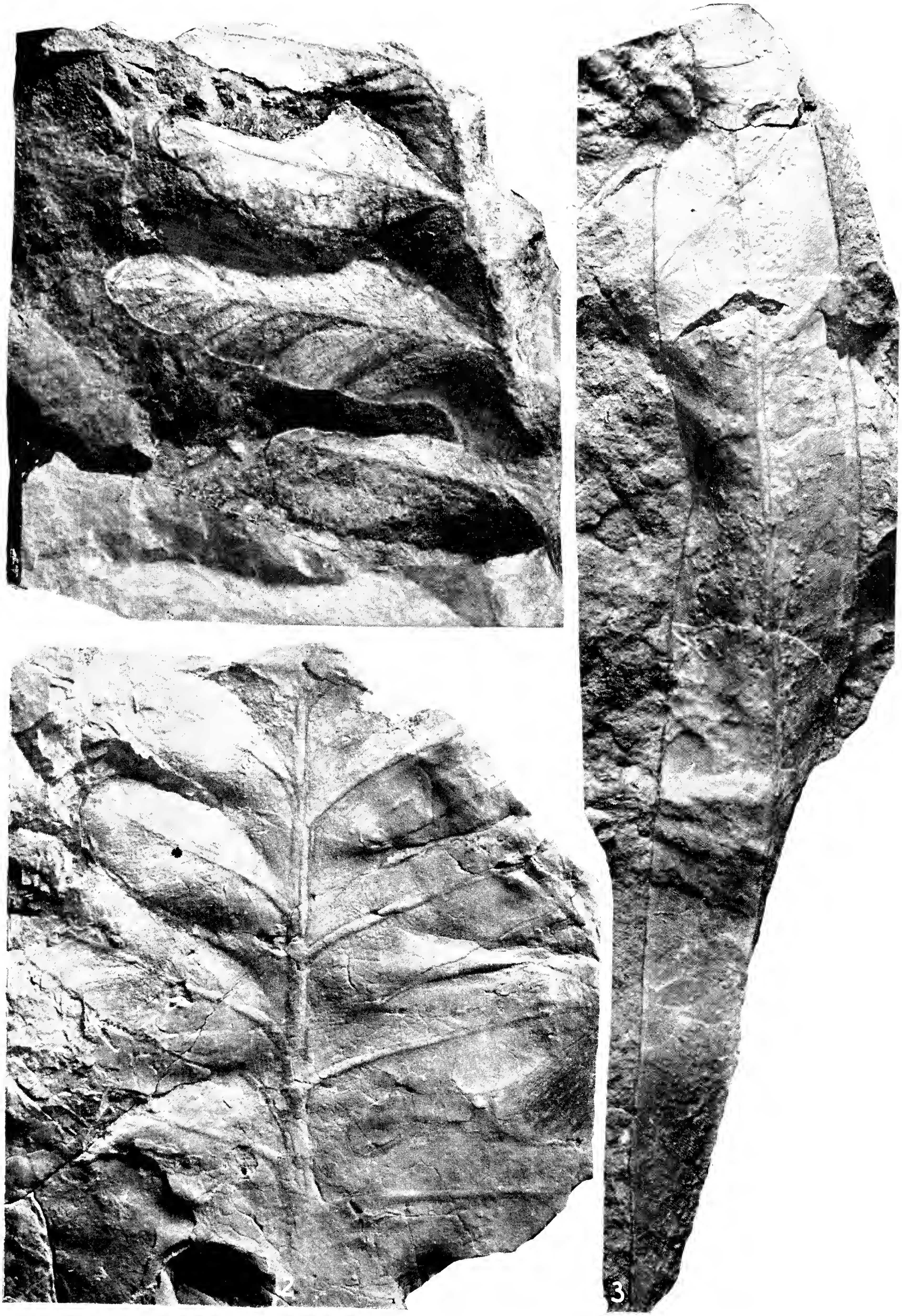
PLATE 31

FIG. 1—*Brongniartites ? yakiensis* D. W., n. sp. Fragment from upper part of pinna in which the pinnules, strongly convex dorsally, are slightly plaited. The trend of the nervation is normal and it is probable that the plaiting is due to a degree of withering. The bordering lamina along the rachis between the pinnules is angularly convex dorsad.

FIG. 2—*Brongniartites ? yakiensis* D. W., n. sp. Segment from near the apex of a pinna which was somewhat macerated and filmed with slime which cracked by drying after exposure to the air.

FIG. 3—*Tæniopteris angelica* D. W., n. sp. Middle portion of one of the long fronds of this species.

All figures in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

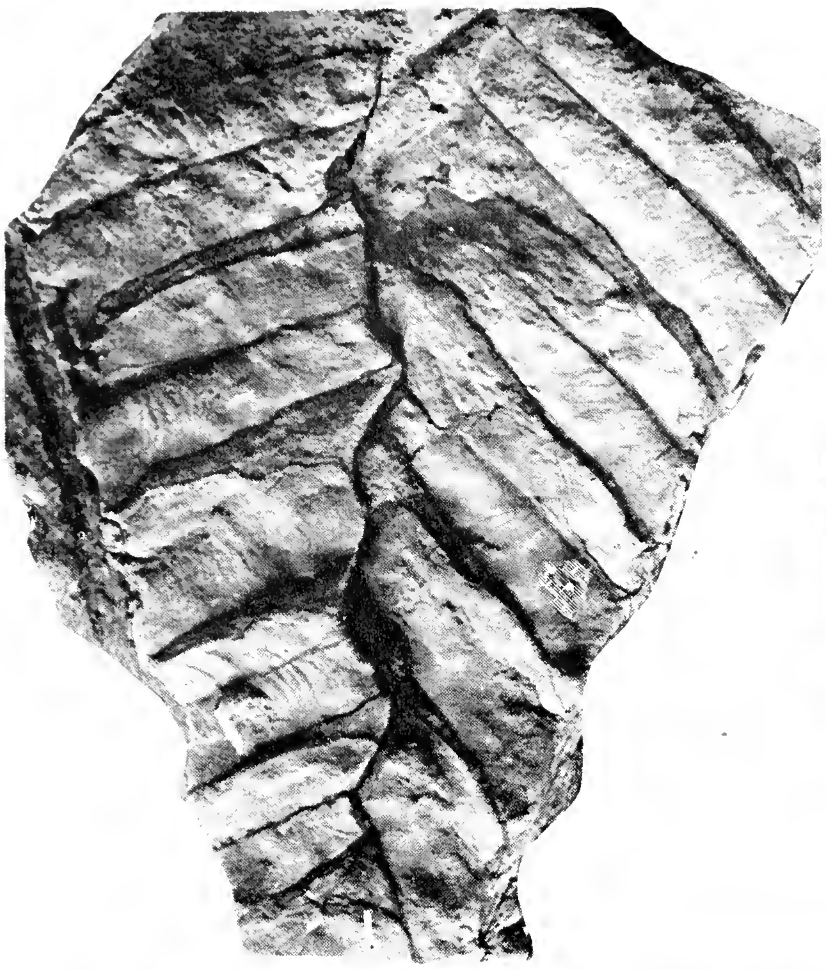
PLATE 32

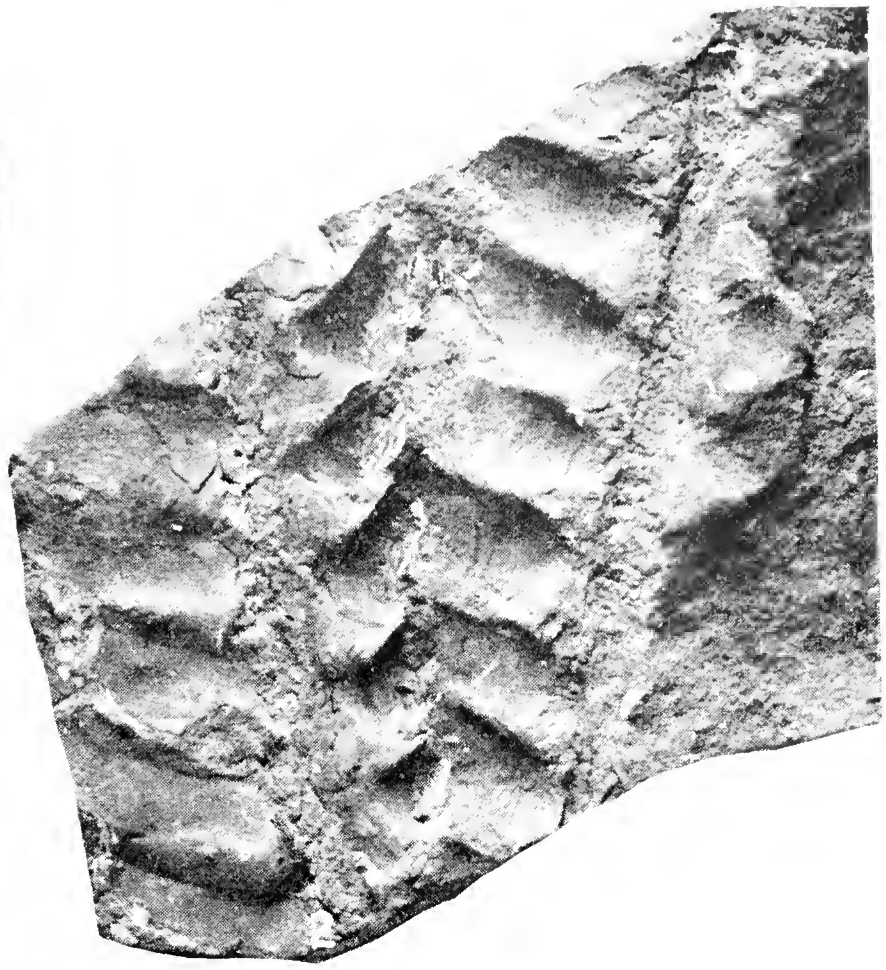
FIG. 1—*Supaia compacta* D. W., n. sp. Portions of the two divisions of the frond a little above the point of bifurcation. In this species the inner pinnules of the two divisions overlap rather broadly. The specimen evidently is somewhat macerated; wrinkling of the leathery epidermis is shown at several points.

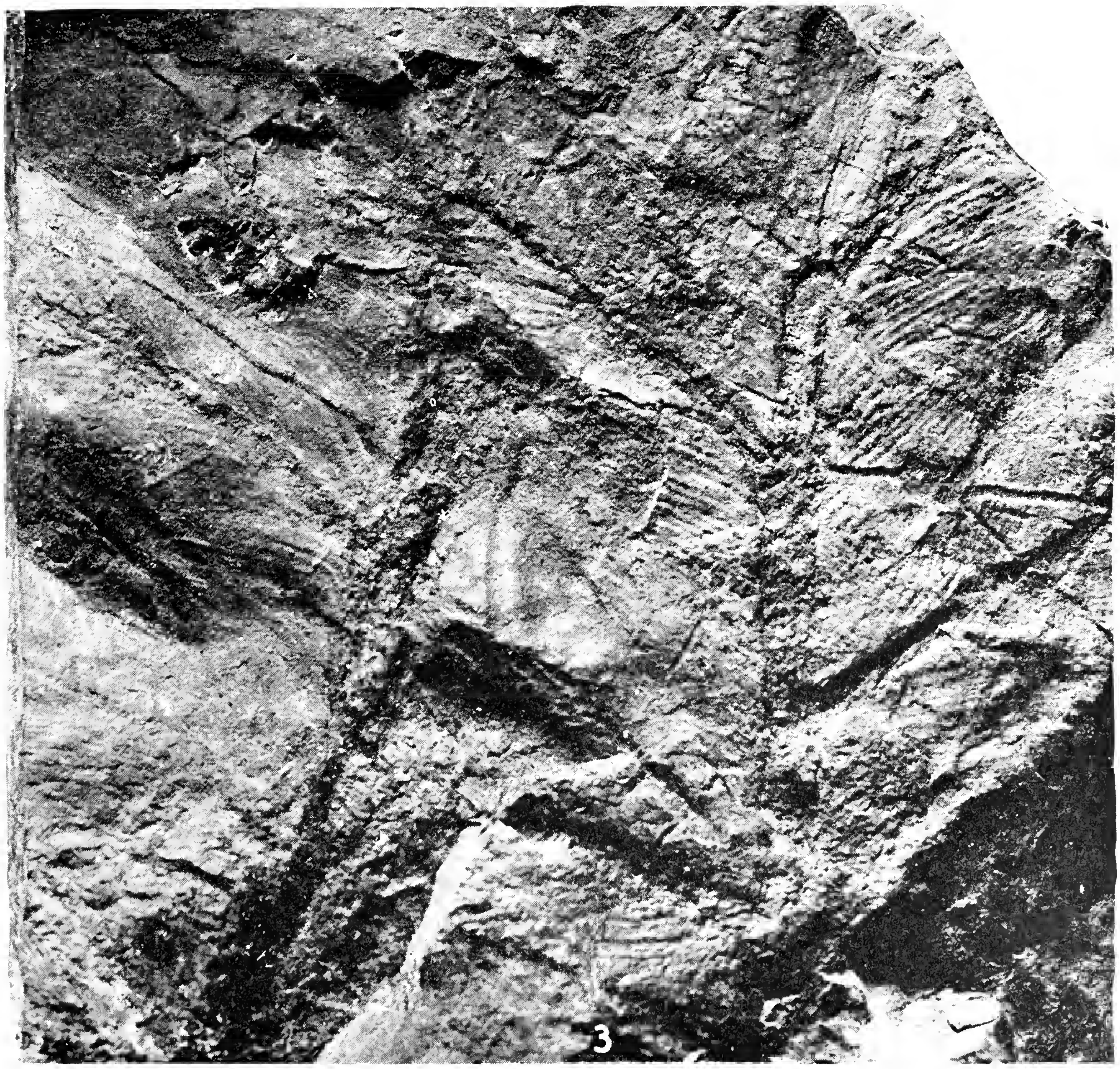
FIG. 2—*Supaia* sp. Fragment of frond near the point of bifurcation, showing the coriaceous and rigid pinnules, the outlines of which are partially seen on the lower left. The impression of the scaly or somewhat spiny dorsal surface of the rachis is plainly visible.

FIG. 3—*Brongniartites? yakiensis* D. W., n. sp. Fragment from the upper part of the frond, in twice the natural size, to show the nervation. Two of the axillary appendages are seen—one traversing longitudinally the upper pinnule on the left, another crossing somewhat diagonally the pinnule in the upper middle of the photograph, which is not retouched.

Figures 1 and 2 in natural size. Figure 3 twice natural size.







Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 33

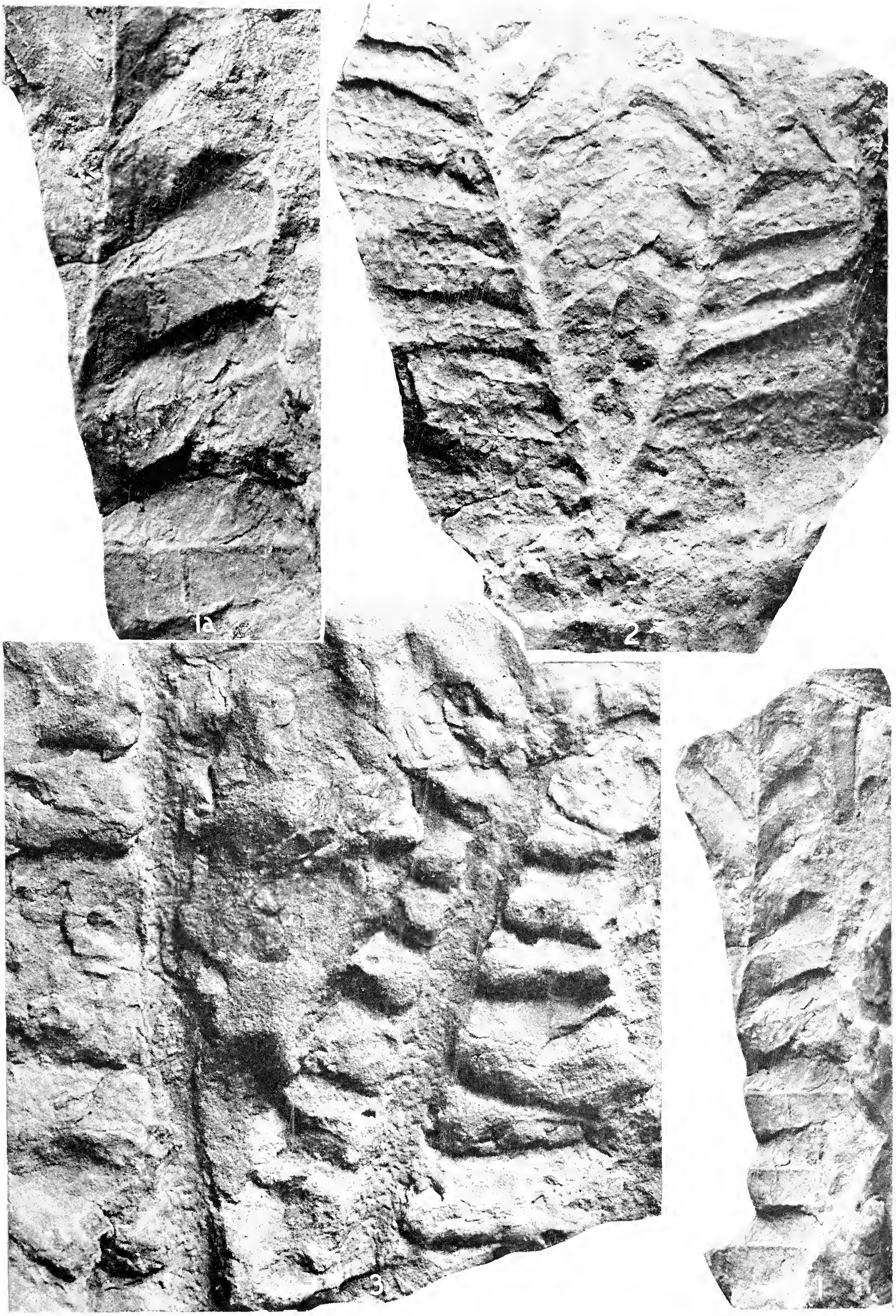
FIG. 1—*Supaia breviloba* D. W., n. sp. Upper portion of a pinna showing the characters and aspect of the obliquely placed Alethopteroid pinnules.

FIG. 1A—*Supaia breviloba* D. W., n. sp. Portion of the same specimen enlarged twice the natural size to show the nervation.

FIG. 2—*Supaia* sp. Photograph in one-half the natural size to show the bifurcation of the frond which was somewhat macerated and smeared with silt before evaporation of the pool in which the frond had fallen had proceeded so far as to cause precipitation of the salty contents of the water. Angular impressions made by cubical saline crystals are clearly seen scattered over the surface of the silt. The crystals went into solution when, after the drought, the pool was refilled and the hollows left by them were filled with sand that came in with the influx of water. The species is indeterminable, but the specimen is possibly referable to *Supaia sturdevantii.*

FIG. 3—*Supaia* sp. indet. Photographed twice the natural size to show the impressions of the coriaceous pinnules and of the chaffy scales and spines clothing the rachis. On the lower right the impressions of scales are also visible on the median nerve.

Figure 1 natural size; Figures 1A and 3 twice natural size; Figure 2 one-half natural size. No figures retouched.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 34

Supaia sp. Slab showing the greater part of a frond of a *Supaia* which was encrusted with mud and partially decayed before burial. It shows distinctly, however, the bifurcation of the frond, and the equality of the divisions.

A cordiform seed lies at the left of the rachis nearly opposite the point of bifurcation. The impression in the muddy silt furnishes ground for the belief that probably the seed was attached to the rachis and is in its place of growth. The aspect and nervation of the best preserved of the pinnules, that near the top of the division on the left, suggest *Supaia merriami*.

Photograph in natural size.

Fossil Plant from the Hermit Shale, Grand Canyon, Arizona

PLATE 35

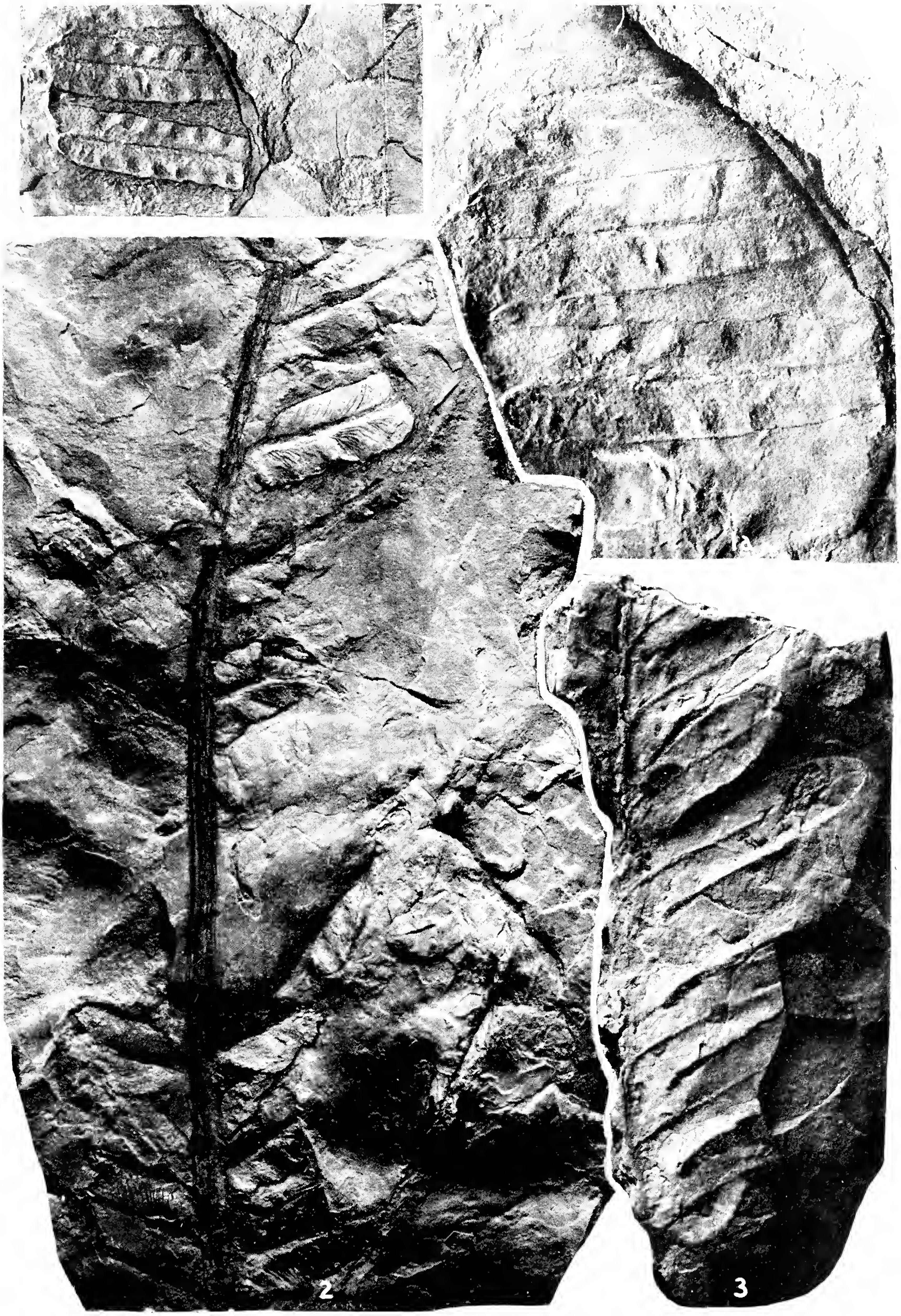
FIG. 1—*Callipteris ?* sp. Impressions of macerated pinnules that evidently were fertile.

FIG. 1A—*Callipteris ?* sp. The same enlarged twice the natural size to show the pit in which fructifications, now disappeared, were placed.

FIG. 2—*Callipteris ?* sp. Fragment of rather badly macerated frond in which the elongated pinnules, possibly referable to *Supaia,* are distinctly cut sublobately on the proximal sides. The fragment represents a species either of *Supaia* or *Callipteris,* the latter seeming more probable, in which the elongated pinnules are becoming pinnatifid. The fasciculate development of the nervation of the newly forming pinnules is indicated in the upper part of the specimen.

FIG. 3—*Supaia compacta* D. W., n. sp. Fragment showing pinnules attached to the rachis in the upper middle of the pinna.

Figures 1, 2, and 3 in natural size; Figure 1A twice the natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 36

FIG. 1—*Tæniopteris coriacea* Goeppert. Fragment of the upper part of the simple frond in dorsal view.

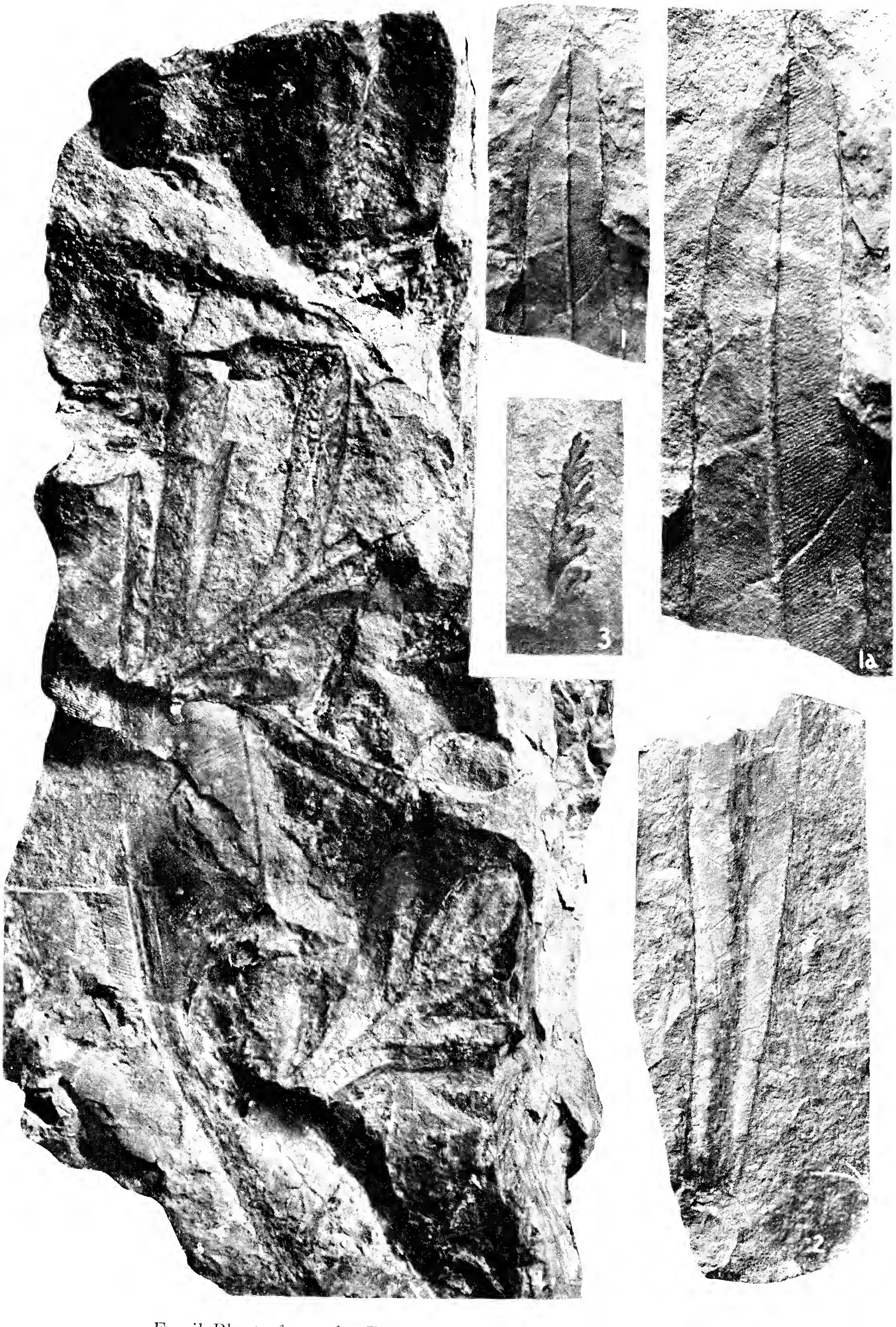
FIG. 1A—*Tæniopteris coriacea* Goeppert. The same specimen, twice the natural size, to show the details of the nervation.

FIG. 2—*Tæniopteris angelica* D. W., n. sp. Lower portion of the frond, showing the gradual narrowing downward to the rather broad attachment.

FIG. 3—*Callipteris raymondi* Zeiller. Fragment of pinna twice the natural size, showing the thick, reduced pinnules.

FIG. 4—*Supaia linearifolia* D. W., n. sp. Apical portions of two pinnæ in the upper of which the extraordinarily rapid elongation of the pinnules is plainly indicated. In the lower left of the photograph is a portion of the leaf of *Tæniopteris angelica* D. W., n. sp., in which the border zone on either size of the ventrally canaliculate rachis is seen.

Figures 1, 2, and 4 in natural size; Figures 1A and 3 twice natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 37

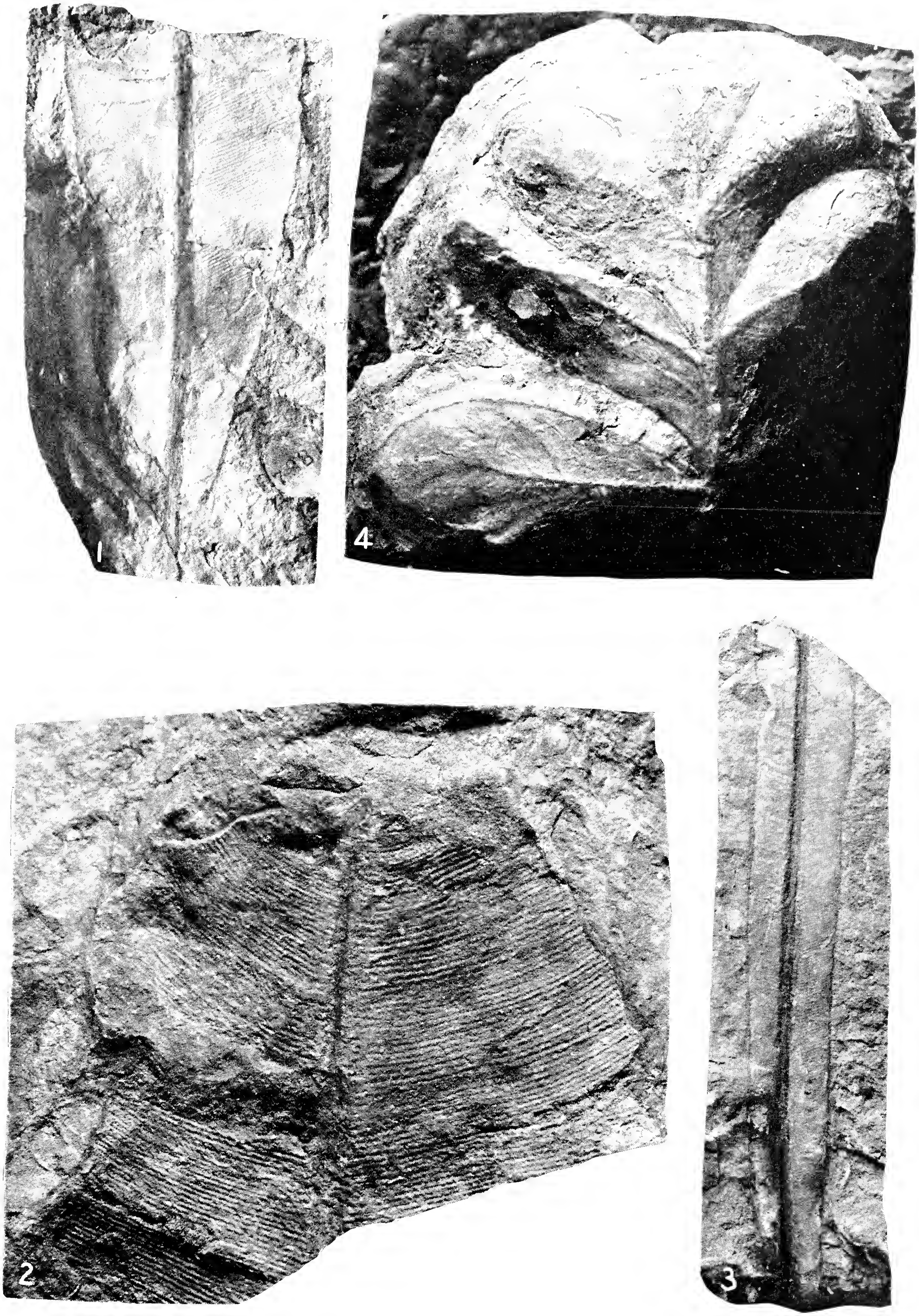
FIG. 1—*Tæniopteris* cf. *eckhardti* Kurtze. Basal portion of a frond showing relatively rapid downward narrowing of the leaf to a short petiole.

FIG. 2—*Tæniopteris* cf. *eckhardti* Kurtze. Upper part of a leaf photographed in twice the natural size to show the coarse, parallel, and slightly upward turned nervation, which does not fork after it leaves the border zone of the rachis.

FIG. 3—*Tæniopteris coriacea* Goeppert. View of the lower portion of a pinna, which narrows very gradually toward the base and is traversed by a strong ventrally rather deeply sulcate median nerve.

FIG. 4—*Brongniartites ? yakiensis* D. W., n. sp. Fragment from just beneath the apex of the frond showing the strong dorsal convexity of the leaf in which the pinnules are spoon-shaped.

Figures 1, 3 and 4 in natural size; Figure 2 twice the natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 38

FIG. 1—*Tæniopteris* cf. *eckhardti* Kurtze. Fragment from the middle of the leaf.

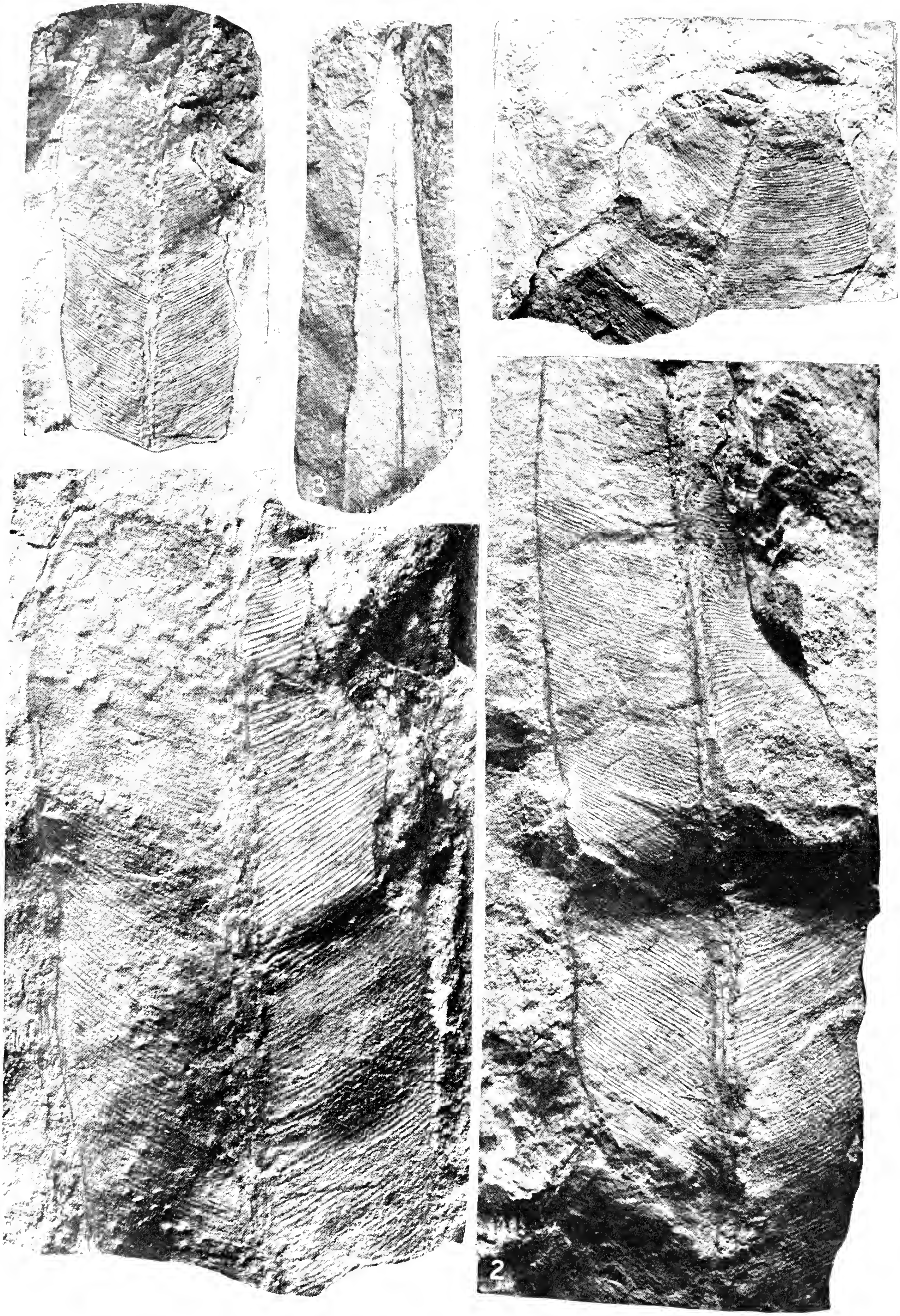
FIG. 1A—*Tæniopteris* cf. *eckhardti* Kurtze, in twice the natural size to show the nervation. The specimen has the aspect of having been infested with a fungus.

FIG. 2—*Tæniopteris angelica* D. W., n. sp. Photograph in twice the natural size for comparison with *Tæniopteris* cf. *eckhardti,* also twice the natural size, in Figure 1A. The difference in the coarseness of the nervation is apparent, though in both species the nerves do not fork except close to the midrib, while they pass outward at nearly the same angle.

FIG. 3—*Tæniopteris coriacea* Goeppert. Apical fragment of the leaf.

FIG. 4—*Tæniopteris* cf. *eckhardti* Kurtze. Slightly mutilated apex of the leaf. Specimen shown twice the natural size in Plate 37, Figure 2.

Figures 1, 3, and 4 natural size; Figures 1A and 2 twice the natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 39

FIG. 1—*Yakia heterophylla* D. W., n. g., n. sp. Fragment showing the ventrally canaliculate and somewhat collapsed axis traversed by the nerve strands from the subordinate pinnæ. The divisions are in spacing and angle characteristic of the species. Most of the leaves, irregular on account of maceration, breakage, or burial of the lobes, are too much inflated to show the nervation.

FIG. 2—*Yakia heterophylla* D. W., n. g., n. sp. Detail showing the irregularity of the lobation of the partially preserved leaves.

FIG. 3—*Yakia heterophylla* D. W., n. g., n. sp. Very young pinna in which the lobes, magnified twice the natural size in the figure, are somewhat twisted so that they appear unduly acute.

FIG. 4—*Yakia heterophylla* D. W., n. g., n. sp. Fragment from upper portion of branch.

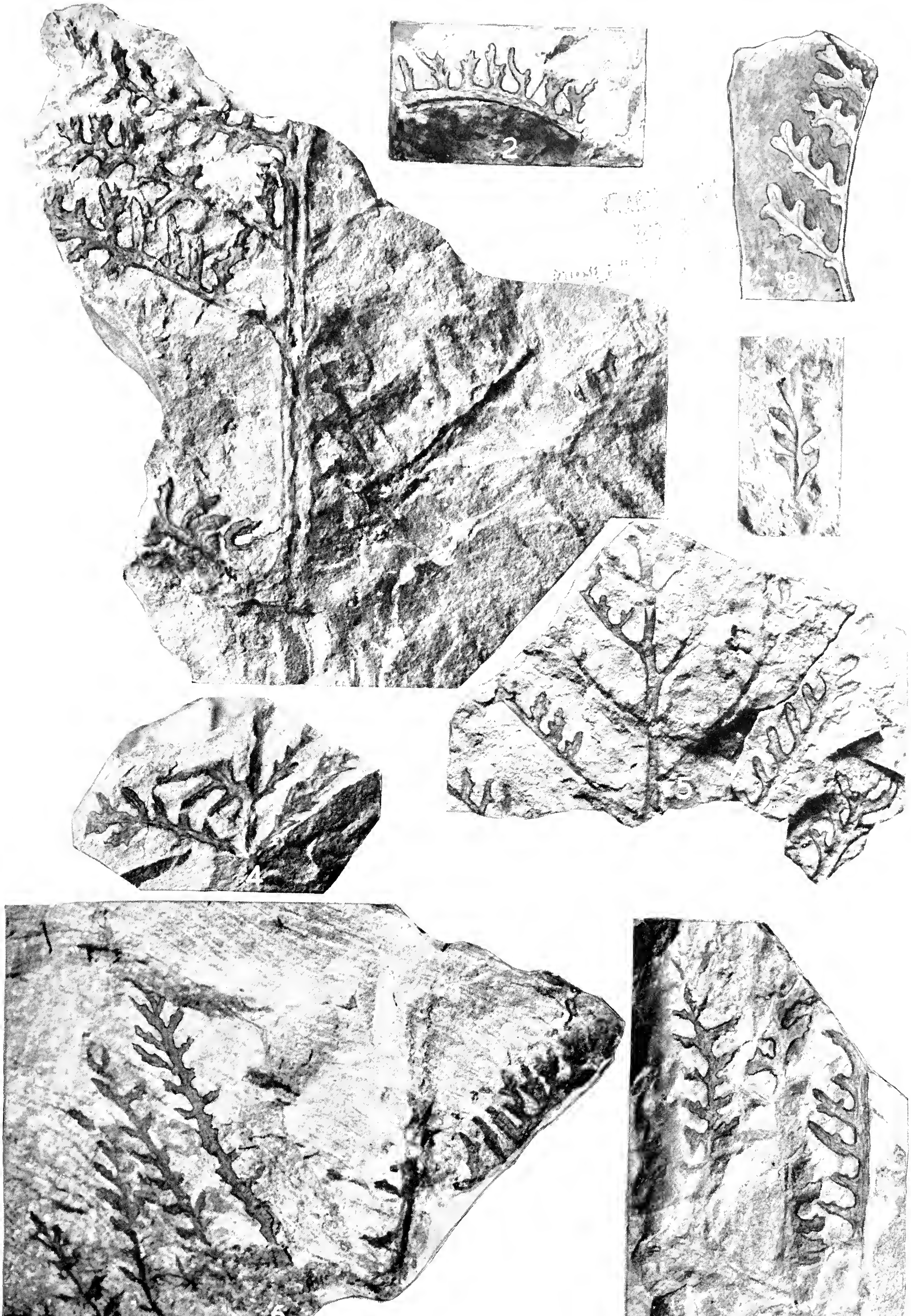
FIG. 5—*Yakia heterophylla* D. W., n. g., n. sp. Mold of upper portion of branch in which the leaves, but slightly sublobate, appear swollen.

FIG. 6—*Yakia heterophylla* D. W., n. g., n. sp. Aspect of many of the pinnæ. Lobation of the pinnules is indicated on the right.

FIG. 7—*Yakia heterophylla* D. W., n. g., n. sp. Portions of parallel pinnæ in which several pinnules, which are not so far macerated or curled, are better shown.

FIG. 8—*Yakia heterophylla* D. W., n. g., n. sp. Small fragment, twice the natural size, in which portions of the pinnules and lobes, but little deformed, are shown.

Figures 1, 2, 4-7 in natural size; Figures 3 and 8 twice natural size.



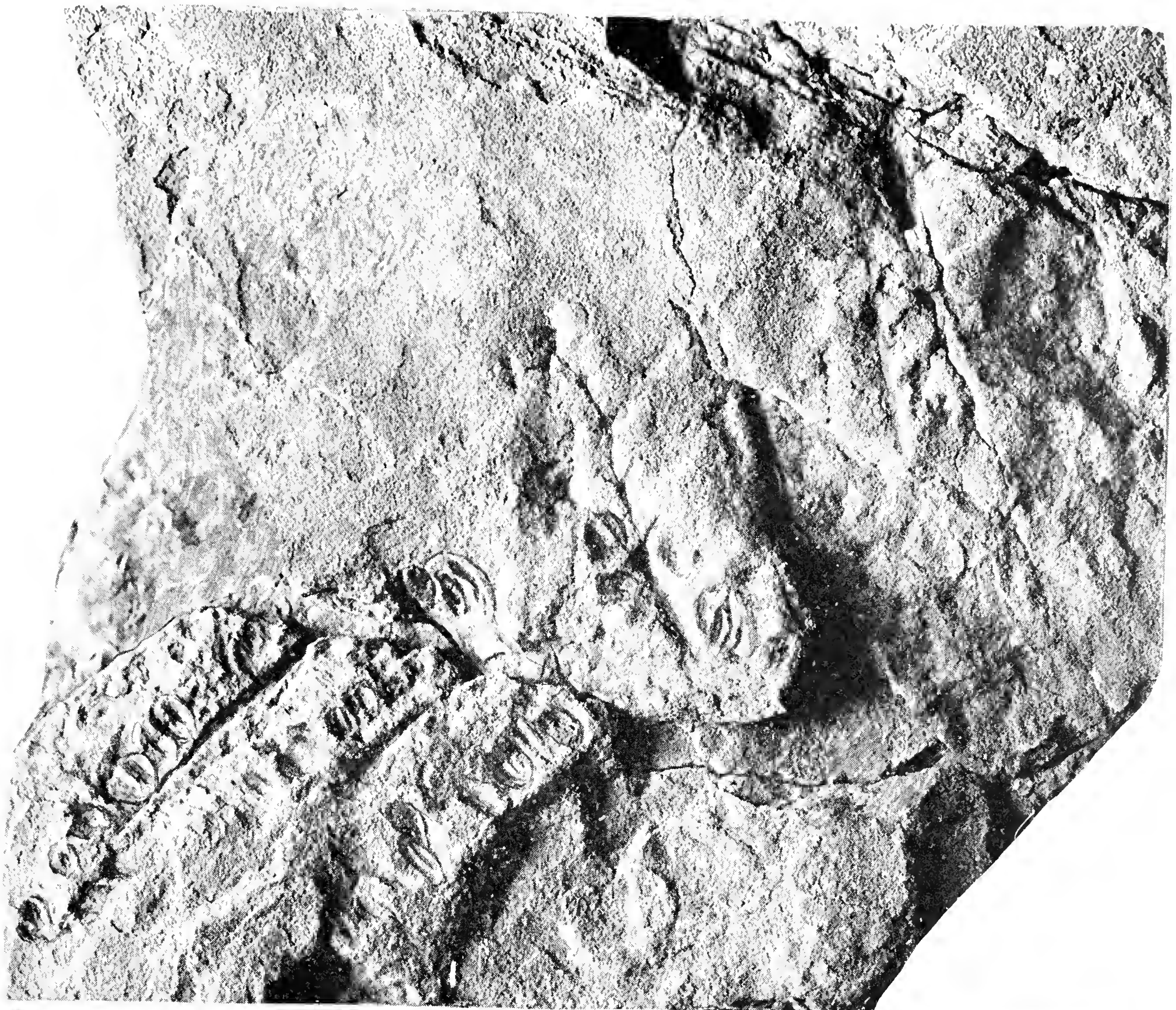
Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

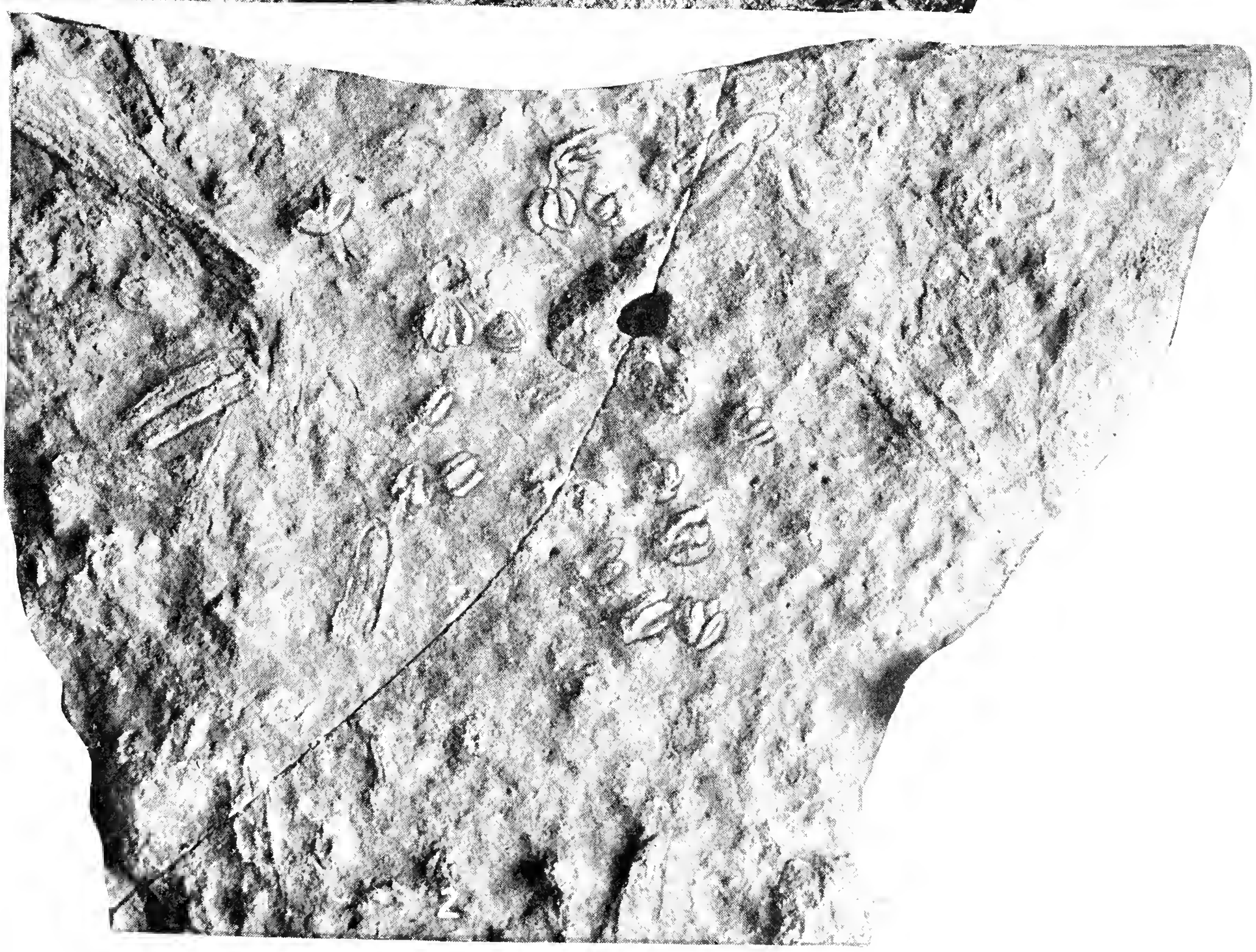
PLATE 40

FIG. 1—*Yakia heterophylla ?* D. W., n. g., n. sp. Remnants of frond in which the spacing and aspect of the pinnæ are in agreement with *Yakia heterophylla*, impressions of whose pinnules and lobes are seen in the upper right. The pinnæ on the lower left, which are tentatively referred to this genus and species, are fertile. They are marked with clusters of elongated, dorsally convex, sporangia (?) attached in pits near the bases of the pinnules. It is possible, however, that these are lobes of an involucre formed by modification of the pinnule, or that they originally surrounded or formed a cupule in which was situated the fruit.

FIG. 2—*Yakia heterophylla ?* D. W., n. g., n. sp. Detached clusters of sporangia (or possibly seeds) growing attached to short pedicils at the base of each cluster and lying longitudinally appressed. The fructification in this fragment, the only one of its kind in the collection, appears to correspond to that shown in Figure 1, though the sporangia, or fruiting bodies, are in this specimen shorter. On the other hand it is possible that in Figure 1 are seen lobed cupules in which fruit clusters like those in Figure 2 were placed.

Both photographs in natural size.





Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 41

FIG. 1—*Walchia piniformis* (Schloth.) Sternberg. Branch showing spacing and angle of the twigs, and profiles of the leaves, which open out at a wide angle a little above the base, and are in some cases but slightly upturned near the apex. Impressions of the large leaves clothing the axes between the ultimate twigs are shown.

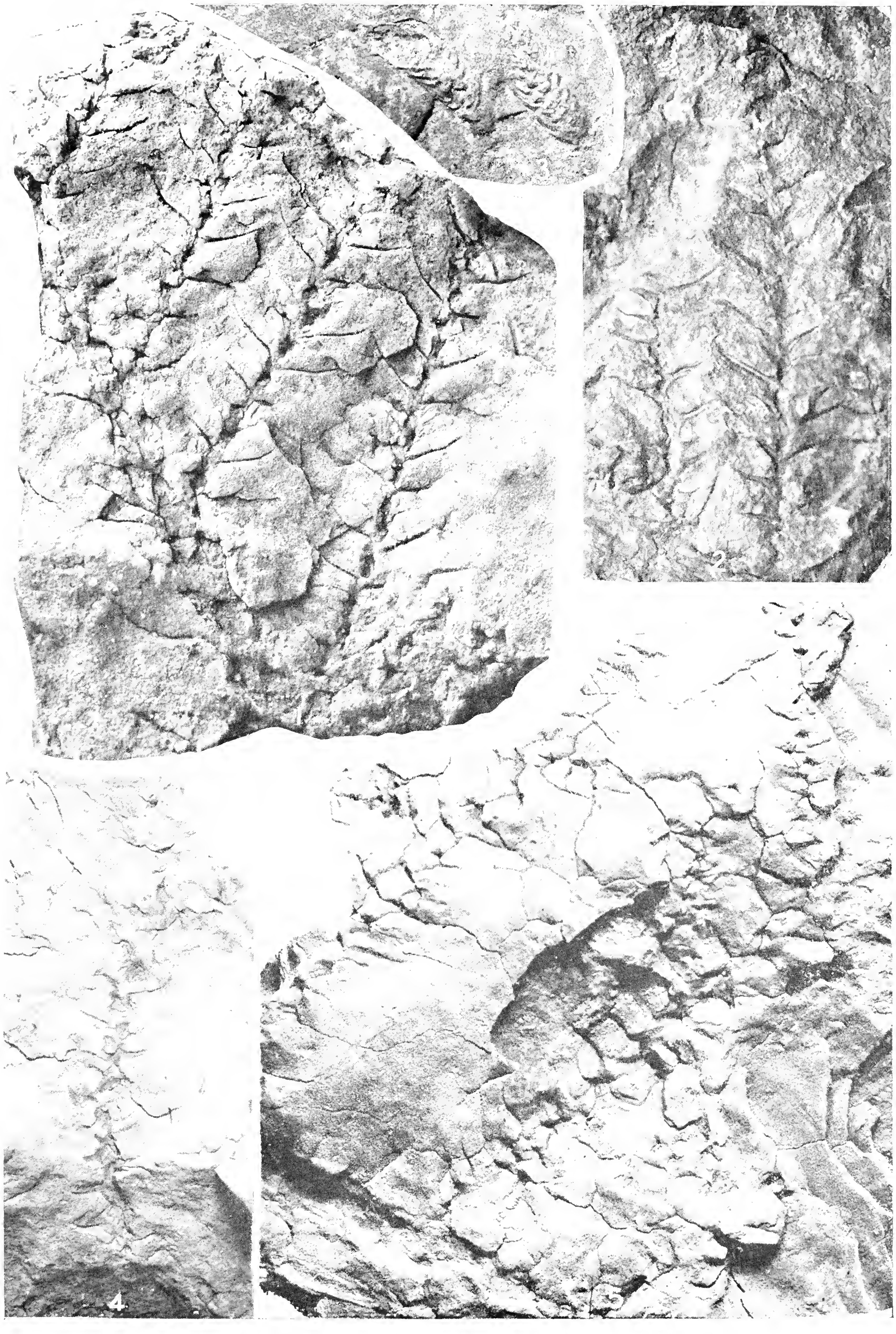
FIG. 2—*Walchia piniformis* (Schloth.) Sternberg. Smaller twigs of more lax habit.

FIG. 3—*Walchia piniformis* (Schloth.) Sternberg. Cones believed to have been borne by this species.

FIG. 4—*Walchia piniformis* (Schloth.) Sternberg. Macerated fragment in which the axis is shrunken as though by collapse of much lacunose tissue.

FIG. 5—*Walchia piniformis* (Schloth.) Sternberg. Impressions of branches showing the very thick and prominent leaf bases and the sharp angles of the leaf.

All photographs in natural sizes.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 42

FIG. 1—*Walchia piniformis* (Schloth.) Sternberg. Part of impression, oblique to the bedding, of largest branch seen, showing the molds left by the rigid leaf bases.

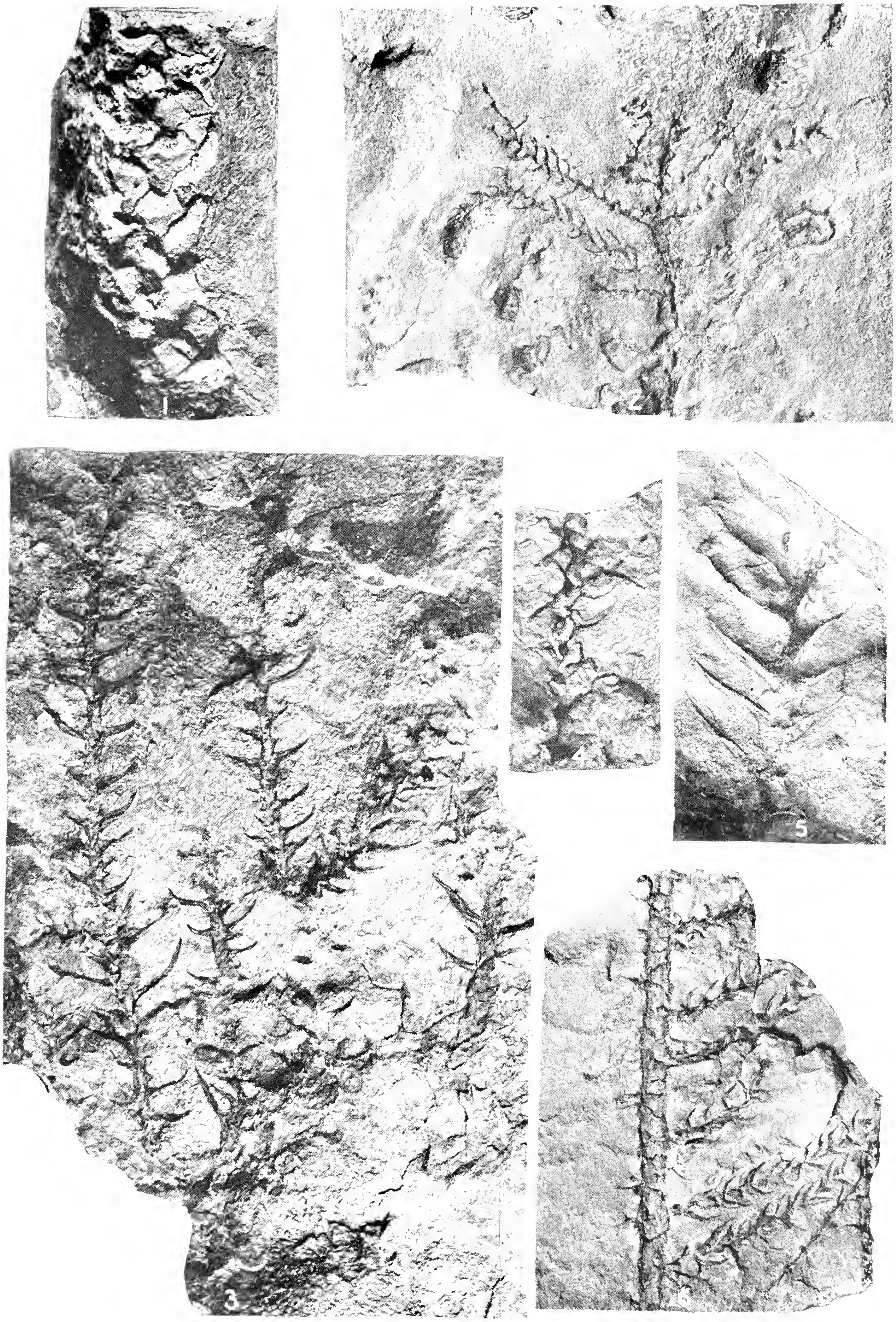
FIG. 2—*Walchia piniformis* (Schloth.) Sternberg. Young twigs partially macerated, bearing immature cones (at left).

FIG. 3—*Walchia piniformis* (Schloth.) Sternberg. Impression of compressed bough of tree in which the leaves are somewhat irregular in position.

FIG. 4—*Walchia piniformis* (Schloth.) Sternberg. Small twig in which collapse of the soft elements of the tissue has caused dislocation of leaf bases and leaves.

FIG. 5—*Walchia piniformis* (Schloth.) Sternberg. Large twig showing lateral and dorsal angles of leaves and prominent leaf bases. The tissue beneath the hard outer bark had evidently collapsed.

FIG. 6—*Walchia dawsoni* D. W., n. sp.? Portion of straight branchlet with distichous, close-spaced lateral twigs, doubtfully referred to this species. In some respects it sugests *W. filiciformis*.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

Plate 43

Walchia dawsoni D. W., n. sp. ? Pinnate branches coated with slime which completely buries parts of the branchlets and adheres to the leaves. The latter are made to appear abnormally thick and rigid. In the upper left of the photograph one side of a pinna of *Callipteris conferta* is so thinly covered as to show the profile of the pinnules and the trend of the median nerves. The current-bearing slime seems to have moved from the left toward the right with reference to the position of the slab.

Photograph in natural size; not retouched.

Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 44

FIG. 1—*Walchia dawsoni* D. W., n. sp. Fragment showing the spacing and alignment of the slender twigs, as in Plate 43.

FIG. 2—*Walchia gracillima* D. W., n. sp. Fragment in which the small leaves are more open and more distinctly curved than they are found in most specimens.

FIG. 3—*Walchia gracillima* D. W., n. sp. Specimen showing the close spacing and angle of the very delicate twigs.

FIG. 4—*Walchia dawsoni* D. W., n. sp. Fragment showing characteristic angle and aspect of the leaves, which are more clearly seen in Figure 4A.

FIG. 4A—*Walchia dawsoni* D. W., n. sp., enlarged twice natural size to show the aspect of the leaves, which are rather thick toward the base, laterally sharply carinate, and strongly upward and slightly inward curved near the apex.

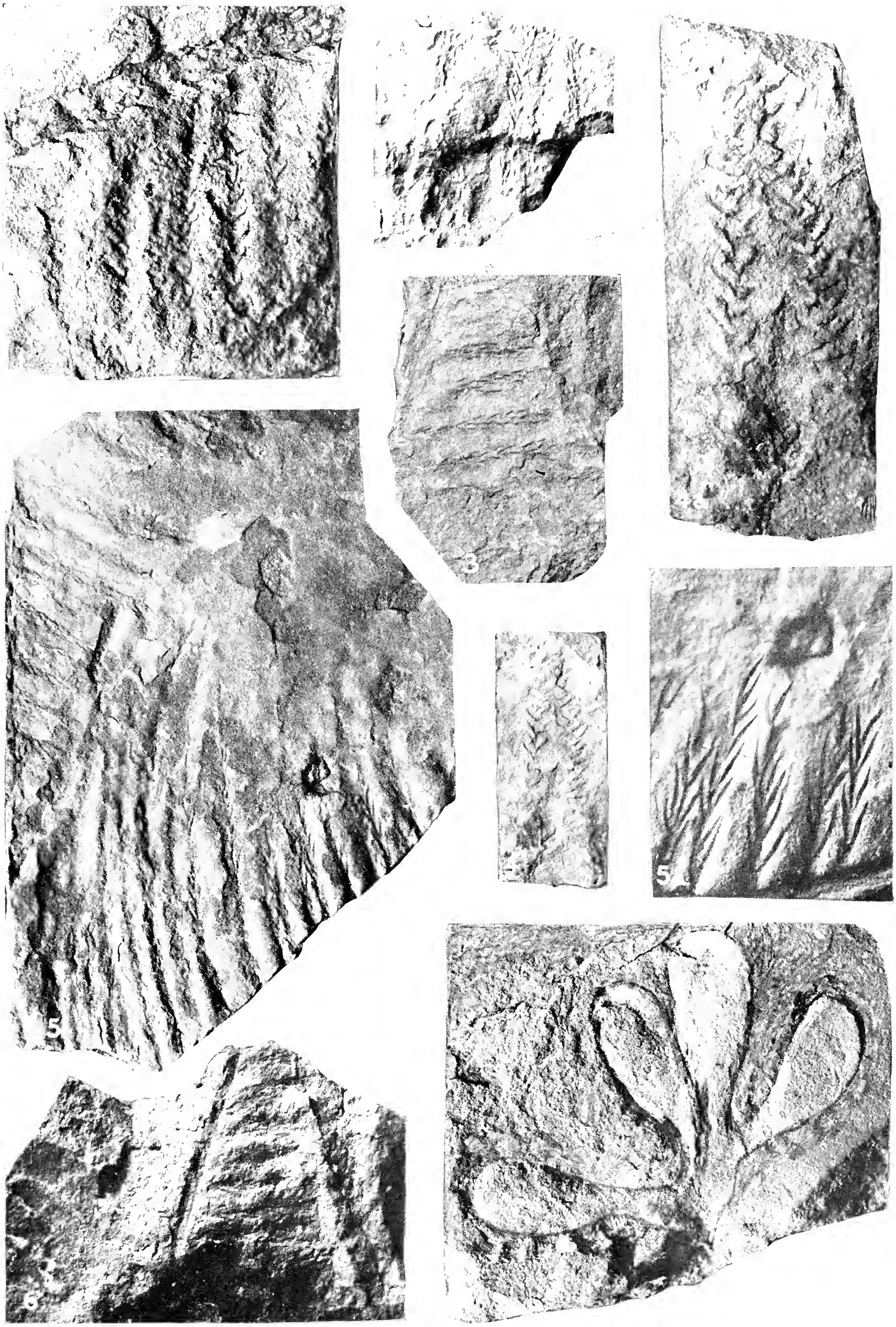
FIG. 5—*Walchia gracillima* D. W., n. sp. Portions of two branches illustrating the extremely delicate, close, parallel twigs which taper very slightly.

FAG. 5A—Photograph of part of the same fragment, twice the natural size, retouched to show the slender, oblique, acute or acuminate leaves.

FIG. 6—*Walchia gracillima* D. W., n. sp. Fragment of apparently narrow elongated branch with slightly drooping, but very close and parallel twigs. The aspect of the twigs in this specimen and in that shown in Figure 5 is characteristic of the species.

FIG. 7—*Psygmophyllum ?* sp. Fragment with slime-covered, downward coalescent lobes attached to an axis oblique to the bedding plane.

Figures 1, 2, 3, 4, 5, 6, and 7 in natural sizes; Figures 4A and 5A twice natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 45

FIG. 1—*Brachyphyllum tenue* D. W., n. sp. Fragment showing gently curved and forking twigs which were, however, so slender as probably to droop.

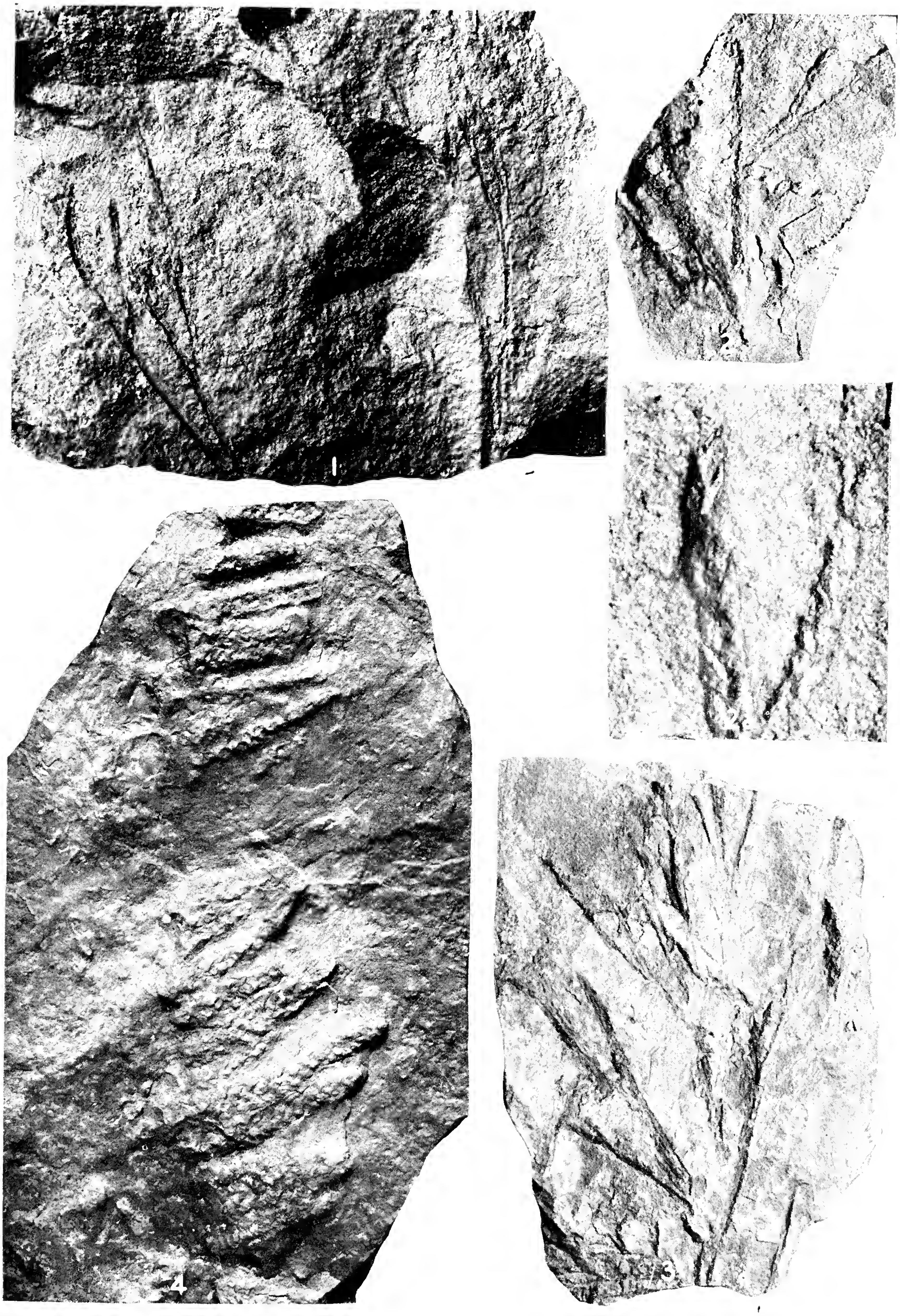
FIG. 2—*Brachyphyllum tenue* D. W., n. sp. Segment lower in the branch showing more frequent division. The axis here photographed is the thickest seen.

FIG. 2A—*Brachyphyllum tenue* D. W., n. sp. Part of the same specimen enlarged twice the natural size to show the closely appressed, minute, imbricated leaves.

FIG. 3—*Brachyphyllum tenue* D. W., n. sp. Fragments of several branches showing a degree of rigidity. In this, as in Figure 1, the leaves of the very slender twigs are so small as not to be clearly visible.

FIG. 4—*Paleotaxites praecursor* D. W., n. g., n. sp. Disheveled fragment in which the displaced twigs are partially buried in the silt. However, the positions and forms of the leaves are indistinctly seen in the upper middle. The imbricated-claw aspect in dorsal view is seen in the lower part of the photograph.

Figures 1, 2, 3, and 4 in natural size; Figure 2A in twice natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 46

FIG. 1—*Ullmannia frumentaria* (Schloth.) Goeppert. A detached blade from bract of cone.

FIG. 2—*Ullmannia frumentaria* (Schloth.) Goeppert. Cone attached to defoliated stem.

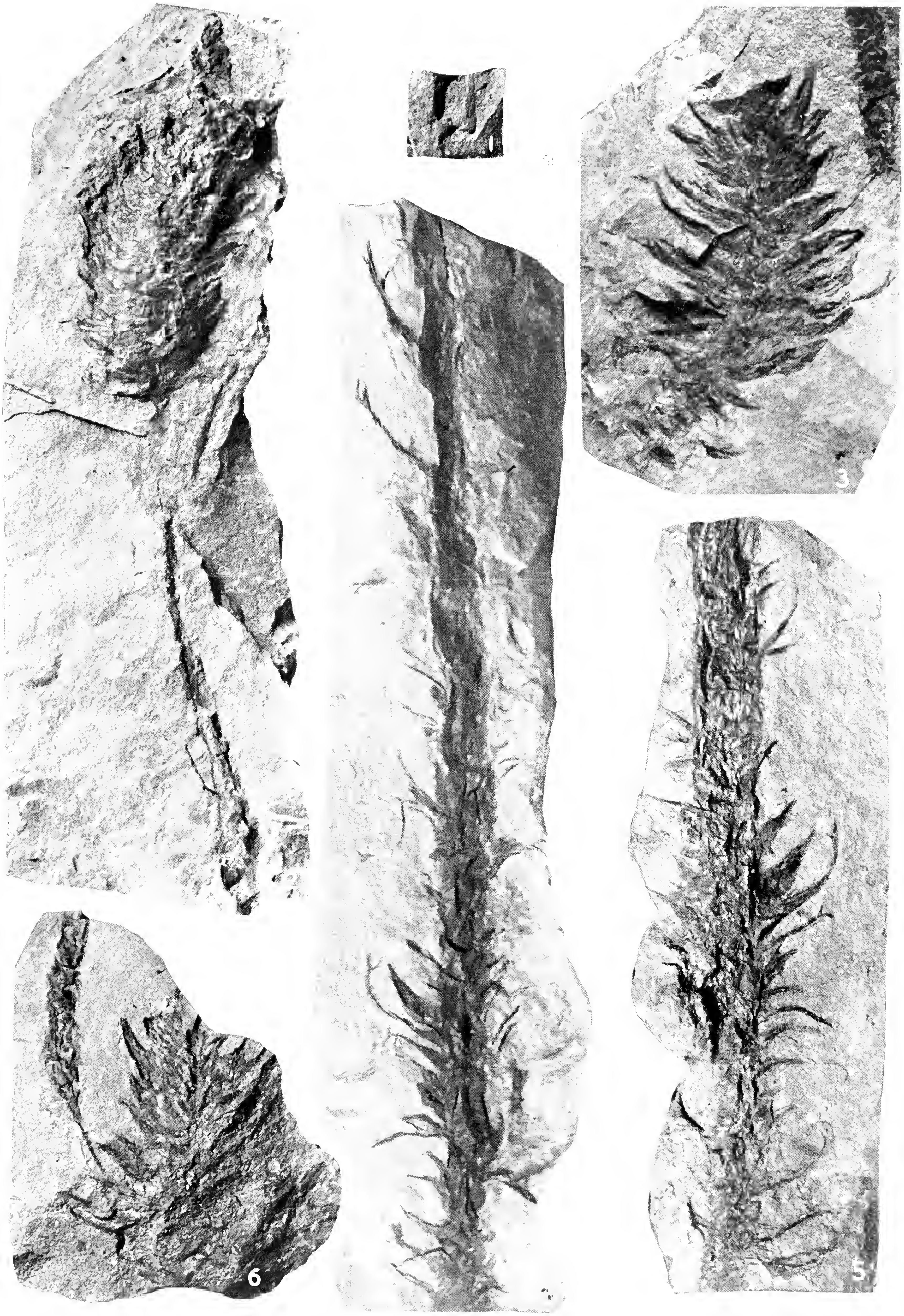
FIG. 3—*Ullmannia frumentaria* (Schloth.) Goeppert. Cone broken across and showing, in the upper part, the elongated blades of the bracts, the basal, seed-supporting portions of which are thickened. Faint impressions of roundish or oval seeds are seen in the lower middle part of the cone.

FIG. 4—*Ullmannia frumentaria* (Schloth.) Goeppert. Foliate stem in which the apices of some of the leaves appear to bifurcate in a manner similar to the leaves of *Buriadica*.

FIG. 5—*Ullmannia frumentaria* (Schloth.) Goeppert. Similar larger stem, less macerated. In this specimen also the leaves indicate probable generic identity with *Buriadica*.

FIG. 6—*Ullmannia frumentaria* (Schloth.) Goeppert. Fragment of cone.

All specimens in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 47

FIG. 1—*Pagiophyllum dubium* D. W., n. sp. Branchlet with parallel twigs.

FIG. 2—*Walchia piniformis* (Schloth.) Brongniart, in which the very open leaves, slightly upturned at the ends, suggest *Walchia filiciformis*.

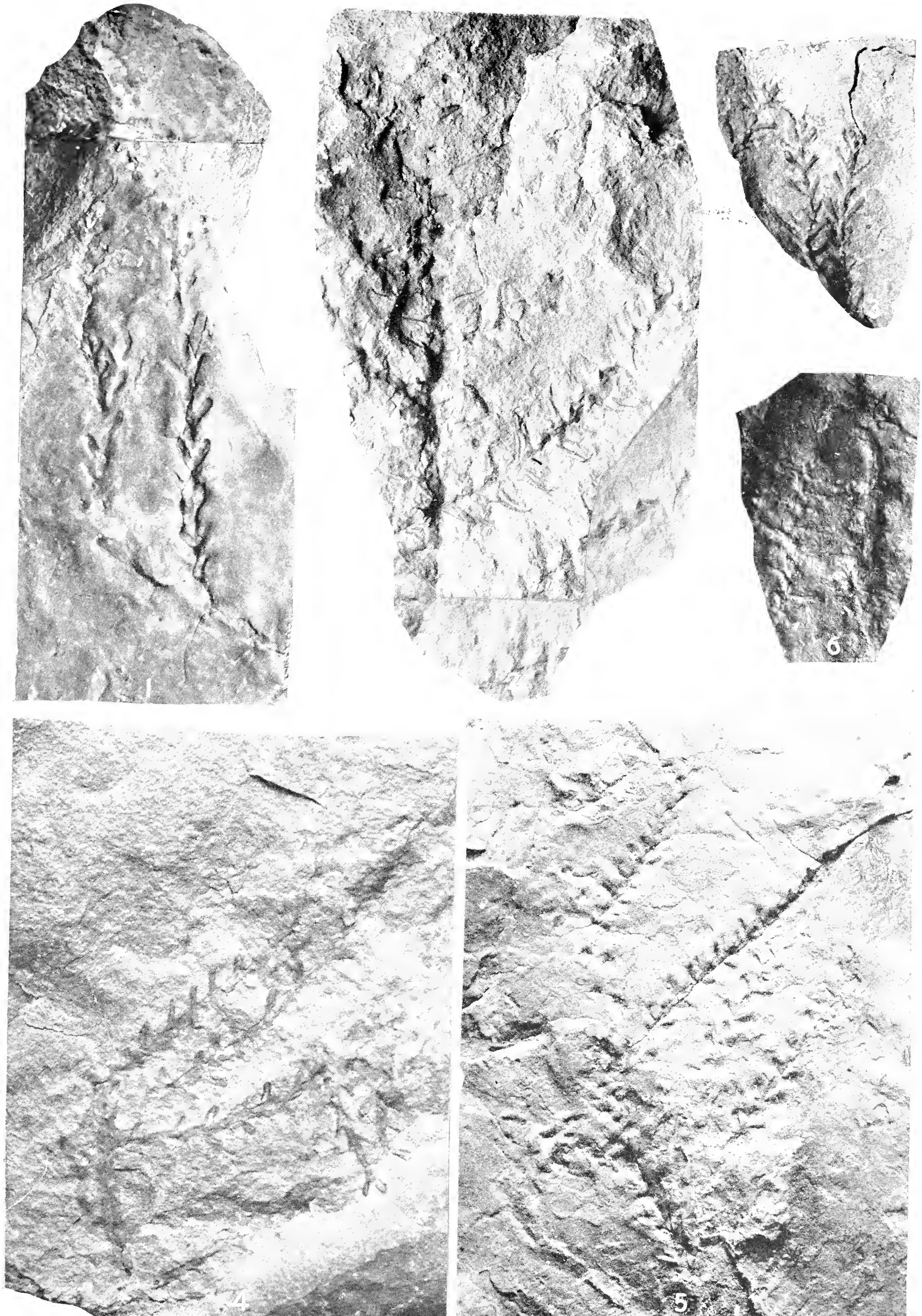
FIG. 3—*Pagiophyllum dubium* D. W., n. sp. Ultimate twigs showing clavate, open, and rather distant leaves.

FIG. 4—*Pagiophyllum dubium* D. W., n. sp. Disheveled fragment in which the leaves, probably representing this species, are seen in profile.

FIG. 5—*Pagiophyllum dubium* D. W., n. sp. In this specimen, which is similar to that shown in Figure 1, the impressions of the leaves have the aspect of a cylindrical body partially enveloped by an acute concavo-convex bract.

FIG. 6—Two twigs of *Paleotaxites præcursor* D. W., n. sp., one of which bears a fruit near the apex. The fruit of this species is better seen in Plate 50.

All figures in natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 48

FIG. 1—*Ullmannia frumentaria* (Schloth.) Goeppert. Part of impression of cone, in natural size.

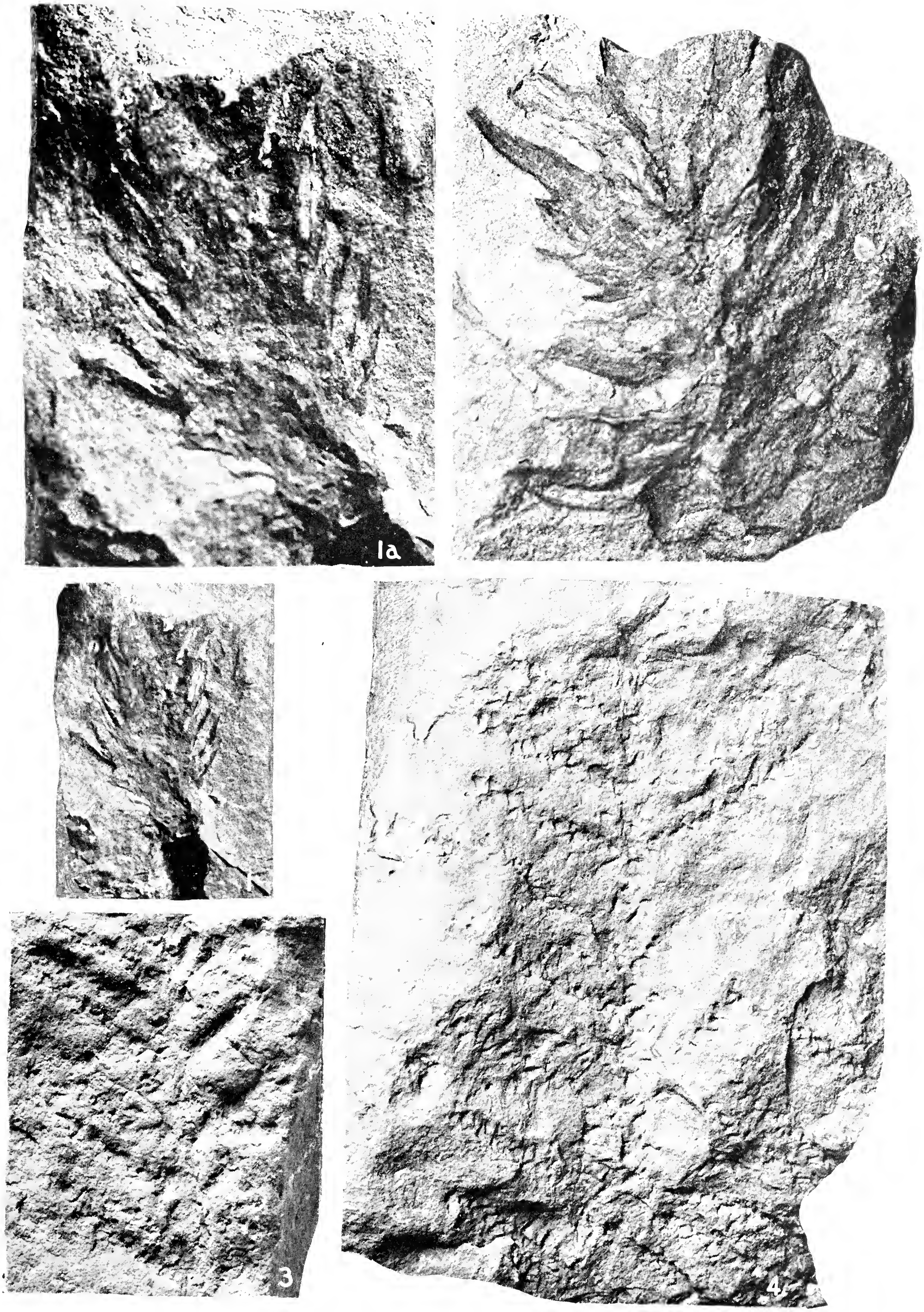
FIG. 1A—*Ullmannia frumentaria* (Schloth.) Goeppert. The same specimen photographed twice the natural size to show the impressions of several round or oval seeds, the mode of attachment of none of which is clear.

FIG. 2—*Ullmannia frumentaria* (Schloth.) Goeppert. Similar cone broken across so as to show the much thickened leaf base, and the surmounting scale, one of which is seen in the middle left. The small round seeds appear to be borne in hollows on the ventral side of the dilated base of the scale. Enlarged to twice the natural size.

FIG. 3—*Paleotaxites præcursor* D. W., n. sp. The photograph which has not been retouched, clearly indicates the pluriseriate spiral arrangement of the twigs in the upper part of a very dense bushy and somewhat rigid branch. The impressions of the thick dorsally rounded claw-like leaves are somewhat clearly shown in portions of the photograph.

FIG. 4—*Brachyphyllum arizonicum* D. W., n. sp. In this photograph the spacing and angle of the distichous twigs, the impressions of the large leaves on the main axis, and the twig leaves, very broad at the base and tapering very rapidly with convex borders and thick upward curved apices, characteristic of the species, are somewhat clearly shown.

Figures 1, 3, and 4 in natural size; Figures 1A and 2 twice natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

Plate 49

Fig. 1—*Paleotaxites præcursor* D. W., n. sp. Fragment from a large branch showing the pits left by the pluriseriate twigs not in the plane of bedding and the short thick claw-like aspect of the leaves which curve upward and inward sharply at the apex. The quadrangular profile of the leaf bases is seen in portions of the specimen.

Fig. 2—*Voltzia ?* — twig. This specimen, photographed four times the natural size, has the appearance of the rather thick, imbricated or appressed, irregularly round-lobed leaves of the type illustrated by some authors as *V. heterophylla*. However, the specimen is very delicate, and its relationship is uncertain.

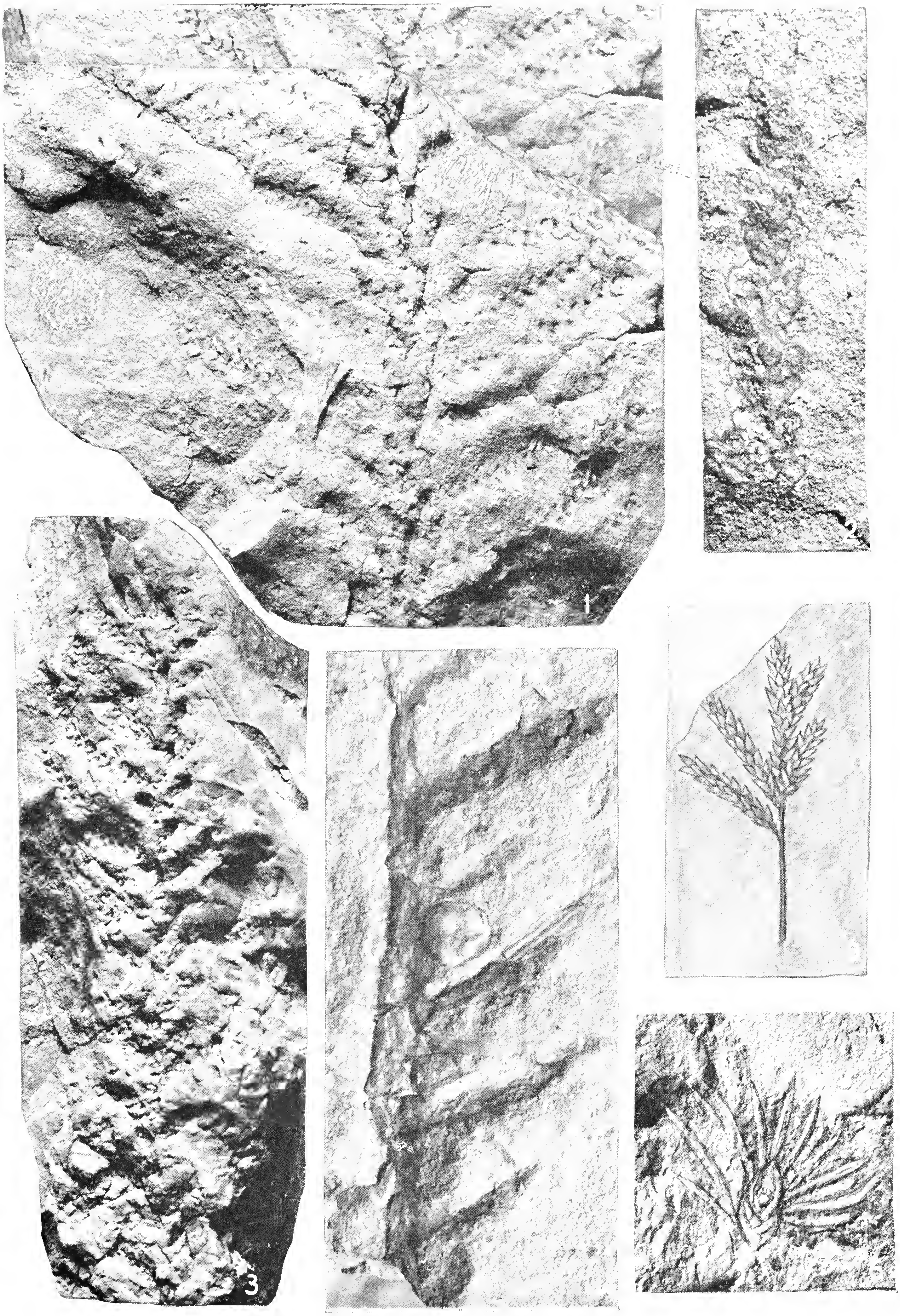
Fig. 3—*Paleotaxites præcursor* D. W., n. sp. Impression of the upper part of a branch densely clothed with twigs in many series. It is plumose in effect, in spite of the relative rigidity of the twigs. The quadrangular impressions of the thick though very small claw-like leaves are shown on the left.

Fig. 4—*Cyclocarpon* sp. This seed, situated in the axil of *Yakia heterophylla,* is shown twice the natural size. The aspect of the impression suggests the possible presence of similar seeds in the axils of other pinnæ.

Fig. 5—*Walchia hypnoides* Brongniart ? Small fragment, twice the natural size, in which the form and arrangement of the leaves on the delicate twigs suggest reference to a young twig of this species. The identification is, however, subject to question. The lower part of the branchlet is stripped of its leaves..

Fig. 6—Impression of apical portion of a coniferous twig with broadly acicular leaves, the only specimen found with this type of leaf. It is provisionally referred to *Taxites.*

Figures 1, 3, and 6 in natural size; Figure 2, four times natural size; Figures 4 and 5 twice natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 50

FIG. 1—*Paleotaxites præcursor* D. W., n. g., n. sp. Fragment from the lower part of a specimen, enlarged twice the natural size to show one of the fruits *in situ* at the end of a twig.

FIG. 2—*Paleotaxites præcursor* D. W., n. g., n. sp. Portion of the upper part of the same branch, also twice the natural size, showing the ends of two twigs, to each of which a large fruit is attached.

FIG. 2A—*Paleotaxites præcursor* D. W., n. g., n. sp. Photographic enlargement, four times natural size, of the fruit seen on the right in Figure 2. In both figures scales or rudimentary leaves are shown adhering to the lower part of the fruit.

FIG. 3—*Carpolithus* sp. In this flattened seed a small round impression above the middle of the nucleus may represent the archegonia.

FIG. 4—*Eltovaria bursiformis* D. W., n. g., n. sp. Capsular pod, probably formed by modification of the pinnule of a Pteridosperm, possibly *Tæniopteris* or *Supaia*. It shows the impressions of what appear to be three seeds, one of which is outlined somewhat distinctly.

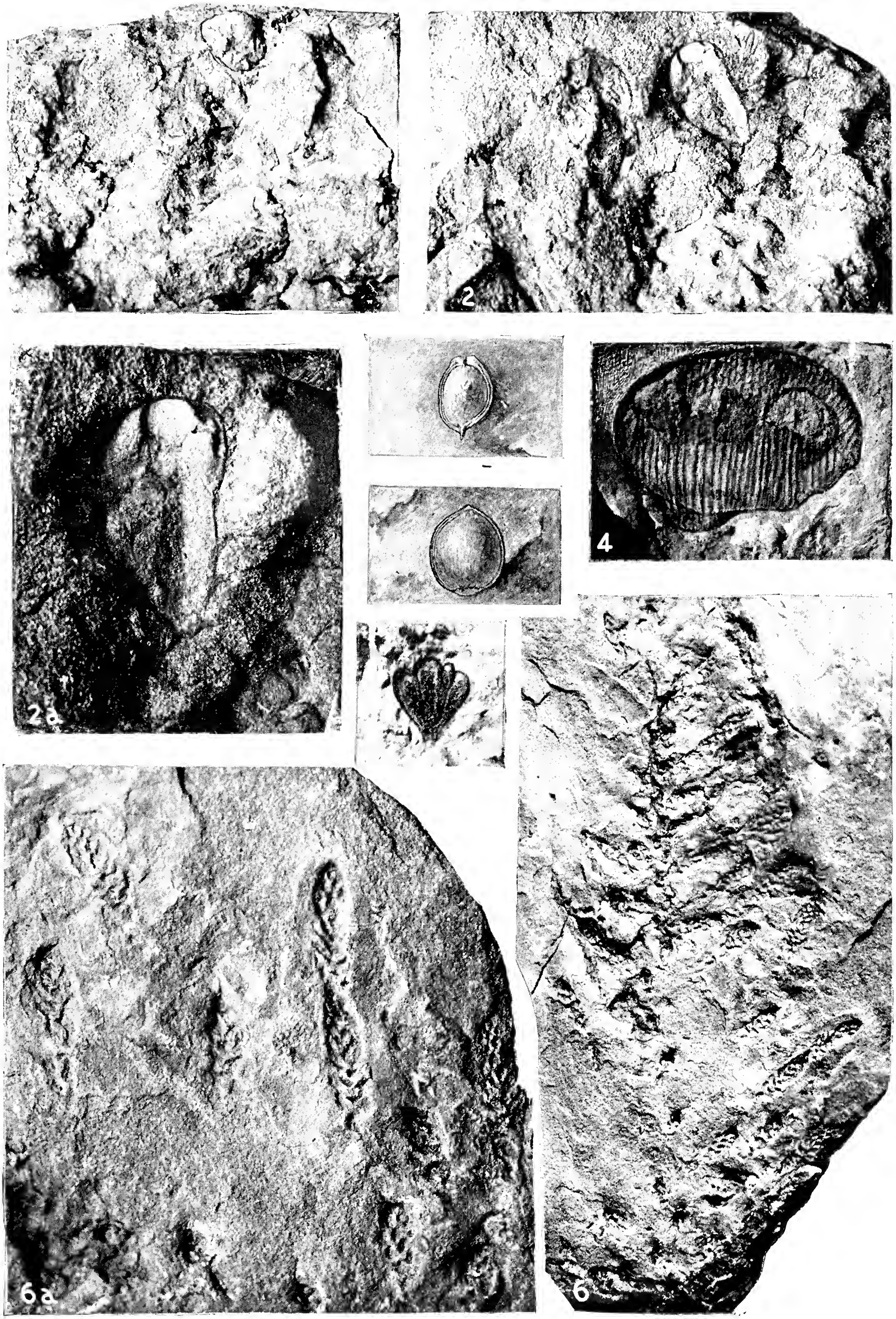
FIG. 5—Lobed scale of *Voltzia* resembling some of the scales from the lower part of the Upper Permian.

FIG. 6—*Paleotaxites præcursor* D. W., n. g., n. sp. Apical portion of a branch showing young twigs bearing buds. The branch lies oblique to the bedding. Consequently the lower part of the rock fragment shows the points of penetration of some of the spirally arranged twigs.

FIG. 6A—Photographic enlargement, twice the natural size, of terminal buds seen on the right in Figure 6.

FIG. 7—*Cyclocarpon angelicum* D. W., n. sp. Flattened seed with very thin vascular envelope. Faint traces of the vascular bundles of an inner seed coat are seen in the lower left of the collapsed fruit.

Figures 3, 4, 5, 6 and 7, natural size; Figures 1, 2, and 6A twice the natural size; Figure 2A four times natural size.



Fossil Plants from the Hermit Shale, Grand Canyon, Arizona

PLATE 51

FIG. 1—*Hastimima* ? sp. Problematical fossil, regarded as the impression of the thick leathery integument of an animal, possibly a crustacean related to the Euripterid *Hastimima*.

FIG. 2—*Typus whitei* Carpenter. Portion of the wing of a Protodonatan insect, found mingled with the plants near the Bright Angel Trail, photographed in natural size. (See F. M. Carpenter, A New Protodonatan from the Grand Canyon: Psyche, Vol. 35, No. 3, 1928, p. 188, pl. v.)

FIG. 3—*Walpia hermitensis* D. W., n. g., n. sp. Tunnels mined by some animal, probably related to the worms or crustacea. They are lined with flattened lenticular pellicles, irregularly crowded or imbricated, that are perhaps to be interpreted as excrementa backed against the sides of the tunnel.

FIG. 4—*Walpia hermitensis* D. W., n. sp. Portions of two tunnels.

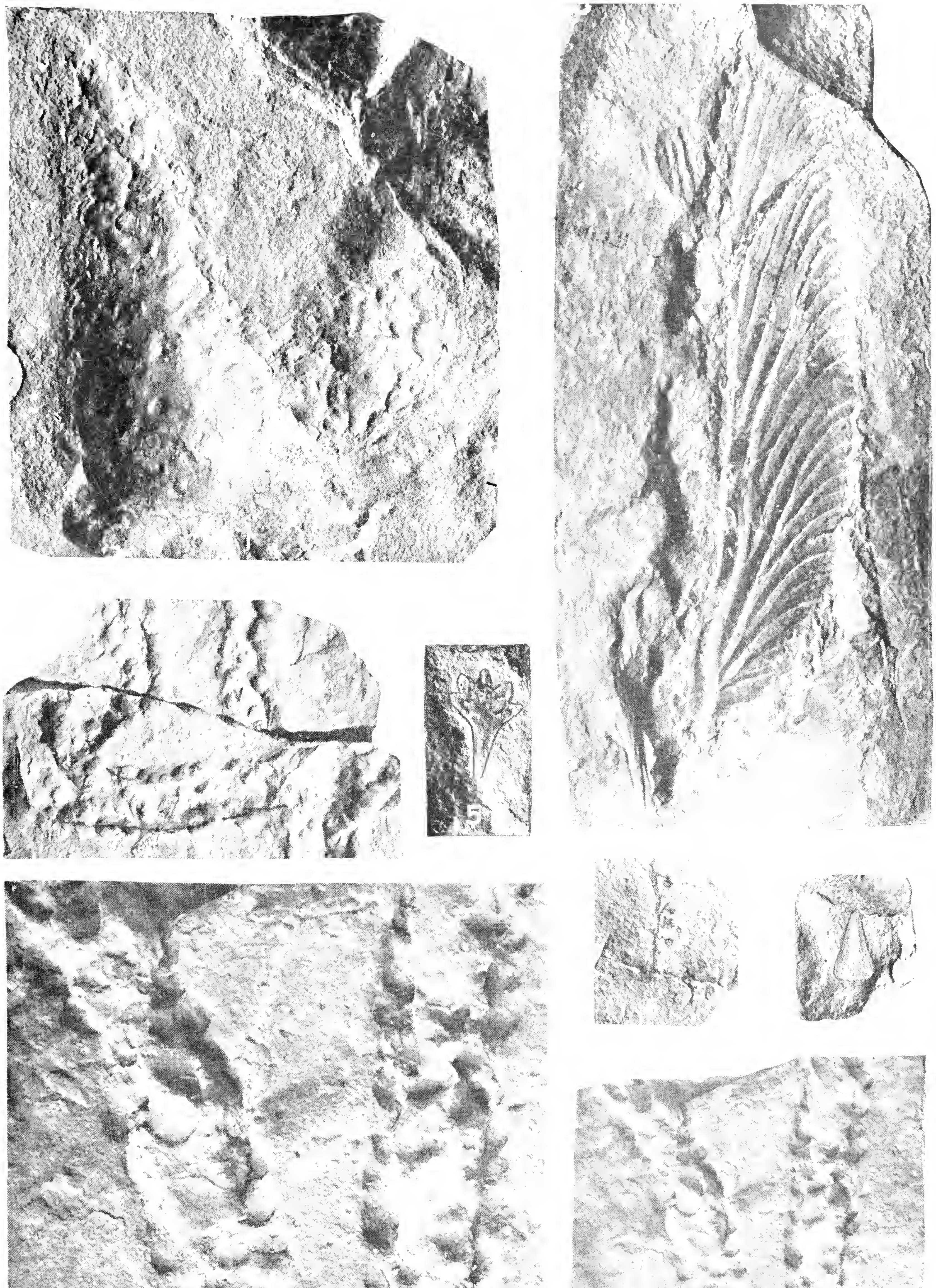
FIG. 4A—*Walpia hermitensis* D. W., n. sp. Photographic enlargement, twice the natural size, to show the mammillary points, one on the thickest part of each of the lenticular bodies

FIG. 5—*Voltzia dentiloba* D. W., n. sp. Dentate lobed scale in which pockets at the base of each lobe mark the locations of seeds.

FIG. 6—Fructification, probably a portion of a coniferous ament, or, less probably, of a sporiferous pinna of unknown relationship.

FIG. 7—*Ullmannia frumentaria* (Schloth.) Goeppert. Bract from cone.

All photographs except 4A in natural size; 4A twice natural size.



Fossils from the Hermit Shale, Grand Canyon, Arizona.